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EXECUTIVE SUMMARY

PURPOSE AND SCOPE

The objectives of this research program are to investigate the flammability behavior of multiple layer fabric assemblies used for draperies and to develop a laboratory-scale test protocol for predicting full-scale fire behavior. The need for such a study arose from a recent awareness that multiple layers of fabrics which individually meet the requirements of NFPA 701 may burn in a manner different from that of the individual layers.

In this project, eight combinations of four drapery fabrics (polyester, cotton, wool, and modacrylic) and two lining fabrics (cotton and blackout) were examined using variants of two established test procedures for single layers: the ASTM D 3659 Semi-Restraint Test Method and the NFPA 701 Large-Scale Test Method. Full-scale experiments, designed to simulate real-world fire performance, were carried out to provide a basis for comparison with the laboratory-scale tests.

In addition, the NFPA 701 Small-Scale Test Method was used to evaluate some of the fabrics which were examined by Belles and Beitel in their work at Southwest Research Institute. A total of 436 individual laboratory-scale and full-scale tests were performed.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions result from this study:

- The NFPA 701 Small-Scale Test adapted to a double layer configuration does not predict the full-scale fire behavior of multiple layer drapery assemblies.

- The ASTM D 3659 Semi-Restraint Test Method, as it is currently written, does not predict the full-scale flammability behavior of multiple layer drapery assemblies.

- The NFPA 701 Large-Scale Test offers at best a limited correlation for predicting the full-scale flammability of multiple layer drapery assemblies.

- For the specific drapery fabric and lining materials examined in this study, those with the present blackout liner burned most severely.

- In full-scale multiple layer drapery experiments, ignition of the side seam where the two panels of fabric are sewn together vertically, appears to result in more severe burns than center ignition.

- Based on the results of this limited study, it is too early to recommend any test protocol for assessing the fire performance of multiple layer drapery assemblies for inclusion in NFPA 701.

Recommendations for future study are as follows:

- Further modifications to the NFPA 701 large-scale and semi-restraint test methods may result in better correlation with the full-scale test results. Consideration should be given to those parameters which the existing tests do not address; for example, rate of heat release, the effect of external radiation, and geometry of the specimen.

- The scope of the multiple layer drapery study should be broadened to include other fabrics and combinations.

- The scope of the multiple layer drapery problem should be broadened to include multiple track systems in order to develop installation guidelines.

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DEVELOPMENT OF A MULTIPLE LAYER TEST PROCEDURE FOR INCLUSION IN NFPA 701: INITIAL EXPERIMENTS

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ABSTRACT

The objectives of this research program are to investigate the flammability behavior of multiple layer fabric assemblies used for draperies and to develop a laboratory-scale test protocol for predicting full-scale fire behavior. The need for such a study arose from recent findings that showed multiple layers of fabrics, which individually meet the requirements of NFPA 701, may present a serious fire hazard. In this project, eight combinations of four drapery fabrics and two lining fabrics were examined using variants of two established test procedures for single layers: the ASTM D 3659 Semi-Restraint Test Method and the NFPA 701 Large-Scale Test Method. The conclusions from this study are that neither of these methods, as currently written, adequately predicts the full-scale fire behavior of multiple layer fabric assemblies. In addition, the NFPA 701 Small-Scale Test Method was used to evaluate some of the fabrics which were examined by Belles and Beitel in their work at Southwest Research Institute. Based on the results of this study, it is too early to recommend any test protocol for inclusion in NFPA 701.

Keywords: ASTM D 3659 Semi-Restraint Test; curtains; draperies; fire performance; flammability; full-scale fire tests; multiple layer fabric assemblies; NFPA 701 Large-Scale Test; NFPA 701 Small-Scale Test; textiles.

1. INTRODUCTION/BACKGROUND

1.1 HISTORY - ORIGIN OF NFPA 701

The National Fire Protection Association (NFPA), on recommendation of the Committee on Fireproofing and Preservative Treatments, adopted requirements for flameproofing of textiles in 1938. The first available edition of this standard, Recommended Requirements for Flameproofing of Textiles, stated that "These requirements apply mainly to fabrics used for decorative or other purposes on the inside of buildings or other structures" [1].[1] This standard described treatments applied to natural fiber fabrics (cotton and wool) which were not resistant to leaching with water or to dry cleaning and required

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[1] Numbers in brackets refer to the literature references in Section 7.

renewal after laundering, dry cleaning, and exposure to the weather. The test method (not unlike the small-scale test in the current edition of NFPA 701) required a small specimen clamped in a metal frame to be exposed to a candle flame for 12 seconds. No pass/fail criteria were included in the document and it was left to the judgment of the regulator as to whether a fabric could be used.

The standard (now under the jurisdiction of the NFPA Committee on Fire Tests) underwent extensive revision in 1966 and in recent years. The current edition [2] applies to flame-resistant materials which are used extensively in the interior furnishing of buildings, in protective clothing for certain occupations and situations, and for protective outdoor coverings such as tarpaulins and tents. Two methods of assessing flame propagation are described. The small-scale test employs a relatively small specimen exposed to a small burner flame for 12 seconds; the acceptance criteria for this test depend on the weight of the material being tested and the application for which the textile is used. The large-scale test requires a much larger specimen exposed to a large burner flame for two minutes; the length of char on the individual folded specimen shall not exceed 35 inches above the tip of the test flame, nor continue to burn for more than two seconds after the flame is removed or exhibit any flaming drips which continue to burn after reaching the floor of the test apparatus. All materials covered in the scope of the standard must be capable of complying with the performance requirements of either the small- or large-scale test or both. The standard states that the authority having jurisdiction shall determine whether both tests are required, depending on the purpose to be served or the nature of the materials tested. In addition, the scope states that "These requirements also apply to multilayered fabrics or assemblies of fabrics." The most recent version of NFPA 701 (1989), however, contains a warning about combinations of multiple layers which may burn more severely than either of the individual fabrics.

1.2 CONCERN ABOUT MULTIPLE LAYERS

Limited experience has shown that multilayered fabrics may burn in a manner which is different from that of the burning behavior of the individual components [3-7]. Many materials may meet the test criteria of NFPA 701 because they shrink away from the flame, melt, ablate, or otherwise fail to support upward flames when heated. However, when such materials are in contact with a material which meets the test criteria of NFPA 701 and does not shrink away from the flame, but instead chars and maintains a degree of structural integrity, the material in question may not be able to evade the flame and could support upward burning. Recent work by Southwest Research Institute and the Center for Fire Research has also shown that combinations of two char forming fabrics, both individually conforming to NFPA 701, can readily burn.

The inclusion of the cautionary statement multiple layer burn behavior in the NFPA 701 standard caused concerns of potential liability within the textile industry, since most draperies are lined but are not tested as multiple layers. This led to the need for the development of an accurate or validated test procedure for multiple layer drapery assemblies. The Center for Fire

Research at the National Institute of Standards and Technology (NIST) was asked by the American Textile Manufacturers Institute, the American Fiber Manufacturers Association, Cotton Incorporated, and the Wool Bureau, to develop such a test procedure. This report describes the initial effort to develop a laboratory test procedure which would correlate with full-scale fire behavior.

1.3 APPROACH

The basic approach of this study was to consider the use of existing test procedures, with appropriate modifications if deemed feasible, to

- evaluate the fire performance of double layers of curtain and drapery fabrics exposed to an open flame source, and
- develop a simple correlation between laboratory-scale fire behavior and full-scale fire behavior.

Full-scale experiments were performed in a real world configuration. Four different drapery fabrics containing fibers of 100 percent generic fiber content were combined with each of two lining materials and exposed to a simulated wastepaper basket fire. These same combinations of fabrics were tested using the NFPA 701 Small-Scale and Large-Scale Test Methods [2] and the ASTM D 3659 Small-Scale Semi-Restraint Test Method [8]. Modifications to each of the methods were introduced to examine the effects of

- varying flame size and exposure time,
- bottom ignition vs. body ignition (both front and back), and
- ventilation.

The extent of damage (char length and area destroyed) and the observation of after flaming and/or flaming drips in the laboratory-scale tests were compared to heat release and area destroyed for the full-scale experiments. Although mass loss was determined for the laboratory-scale tests, it was not practical to determine the mass loss for the full-scale drapery assemblies.

2. EXPERIMENTAL PROCEDURES

2.1 MATERIALS

Four drapery fabrics and two drapery liners were used in the study, for a total of eight fabric or double layer combinations. The drapery fabrics selected for experimentation were an FR (fire retardant) polyester, an FR wool, an FR cotton, and an FR modacrylic. The lining fabrics were an FR cotton and an FR vinyl blackout or vinyl coated fabric. Each of the fabrics selected for the study had been certified to pass NFPA 701 in a single layer test.

The polyester drapery fabric selected is an inherently flame resistant Trevira[2] polyester treated with a proprietary phosphorous compound. The fibers have a pentalobal cross-sectional shape. The filament warp and fill yarns are 830 denier, woven into a plain weave with 28 x 28 yarns per inch.[3] The fabric is opaque and tightly woven. The yarns are semi-dull and dyed gray. The finished goods are 66 inches wide and have an areal density of 8.5 oz/yd^2.

The cotton drapery fabric selected is a topically-treated fabric with a non-durable ammonium polyphosphate finish. The ammonium polyphosphate finish has an estimated 75 to 80 percent finish pick-up; the treatment was applied by dipping the fabric into a 32.5 percent concentrated aqueous solution bath and squeezing out the excess. The fabric is a plain weave duck cloth with 88 warp yarns per inch and a fill of 28 yarns per inch. The fabric is opaque and rather dense or tightly woven. The warp yarns consist of a 1-ply/16-hank and the fill yarns are 1-ply/7-hank, both having a Z-twist. The fabric has an areal density of 7.0 oz/yd^2, is 54 inches wide, and is not dyed.

The wool drapery fabric selected is approximately 48 inches wide and has an areal density of 8.0 oz/yd^2. The fabric is constructed as a plain weave with a warp of 30 yarns per inch and a fill of 22 yarns per inch. The fabric appears moderately opaque, but light can pass through the weave. The yarn consists of a 2-ply/20 hank S-twist worsted wool. The flame retardant property of the fabric was achieved through the treatment of the fill yarns with a Zirpro[2] flame retardant finish. The warp yarns were untreated. The yarns are dyed a creme color.

The modacrylic fabric selected is inherently fire resistant and made from SEF modacrylic yarns. The yarns are 2-ply/8-hank with an S-twist. The fabric is approximately 48 inches wide and has an areal density of 8.3 oz/yd^2. The fabric is rather loosely woven and transparent. The fabric has a warp of 14 yarns per inch and a fill of 17 yarns per inch. The fabric is green in color. The fabric was woven and run on a tenter frame to be heat set for 30 seconds at 240 °F.

The cotton liner fabric selected was treated with a non-durable flame retardant finish. The fabric weighs 3.4 oz/yd^2 and is 48 inches wide. The warp yarn count is 80 yarns per inch and fill count is 64 yarns per inch. The fabric is lightweight but tightly woven. The fabric is white in color. The yarns are made of a 1-ply/28-hank, the fill yarns are 1-ply/33-hank, both having a Z-twist.

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[2]Certain commercial products are identified in this report in order to adequately specify the materials used. Such identification does not imply recommendation by the National Institute of Standards and Technology, nor does it imply that these materials identified are the best available for the purpose.

[3] English units are used for description of the fabrics because of customary usage by the textile industry.

The blackout liner selected was described as a three-pass blackout consisting of a white scrim fabric of 50 percent polyester and 50 percent cotton fibers in which a thin foam backing is attached to the scrim. The backing layer is white in color. The fabric weighs approximately 10.6 oz/yd^2 and is 48 inches wide. The scrim fabric has a warp count of 78 yarns per inch and a fill count of 48 yarns per inch. The fabric is very opaque. The foam backing is attached to the scrim fabric by means of a heat setting process.

2.2 METHODS OF INVESTIGATION

The research utilized full-scale drapery experiments and several published test methods, including the NFPA 701 Small-Scale Test Method [2], ASTM D 3659 Small-Scale Semi-Restraint Test Method [8], and the NFPA 701 Large-Scale Test Method [2].

In each of the methods of investigation described below, the fabrics were tested with the warp direction vertical because this is common practice for curtain and drapery fabrics and this project is concerned only with these materials.

2.2.1 Full-Scale Experiments

In the work reported by Belles and Beitel performed at Southwest Research Institute [6], the full-scale drapery experiments were performed in an essentially open environment. The draperies were mounted on a gypsum board wall, 8.5 feet (2.6 m) high by 12 feet (3.7 m) wide, with a 3 foot (0.9 m) overhang at the top. The wall was erected in a 40 foot (12.2 m) by 90 foot (27.4 m) enclosed room having a 25 foot (7.6 m) high ceiling. Eight foot (2.4 m) long by 16 foot (4.9 m) wide draperies were pleated to a width of approximately 5 feet (1.5 m) and hung on the center of the 12 foot (3.7 m) gypsum wall. A bunsen burner with a circular tip 3/8 inches (9.5 mm) in diameter provided the fire exposure. The burner tip was about six inches (152 mm) above the floor and produced a diffusion flame 8 to 12 inches (203 to 305 mm) high. The tip was level with the bottom of the test specimens so that the burner flame exposed 8 to 12 inches (203 to 305 mm) of the specimen. The fire exposure was generally maintained for five minutes or until flames reached the simulated ceiling.

We chose to conduct our full-scale experiments in an open-door room environment to simulate more closely a real world fire situation (Figure 1). The room, lined with ½ inch (13 mm) thick inorganic fiber-reinforced calcium silicate board and having a concrete floor, was 8 feet (2.4 m) wide by 12 feet (3.7 m) long and had an 8 foot (2.4 m) high ceiling. A 30 inch (0.8 m) wide by 80 inch (2.0 m) high door centered on one 8 foot (2.4 m) wall was the only source of ventilation to the room. The 8 foot (2.4 m) long by 16 foot wide sewn and pleated draperies were hung on the 8 foot (2.4 m) wall opposite the open door. The ignition source was a simulated wastepaper basket fire using a porous burner (7 inches by 10 inches) (178 mm by 254 mm) placed against the drapery; a 50 kW propane gas diffusion flame impinged against the drapery

about 6 inches (152 mm) above the floor for 200 seconds. Only one test of each fabric pair was conducted.

During the course of the fire, the effluent from the room was collected in a 3.7 m by 4.9 m hood connected to an exhaust stack having an exhaust flow capacity of about 3 m^3/s. Temperature, velocities, and oxygen and carbon dioxide in the exhaust collection hood were monitored to provide for rate of heat release measurements [9]. With these measurements, Huggett [10] and Parker [11] detail a method to determine the rate of energy production of the fire based upon oxygen consumption calorimetry. Smoke density measurements were also made in the stack. A thermocouple tree was installed in the room to provide a temperature profile from floor to ceiling. Two radiometers were mounted on center of the rear wall behind the draperies at the 4 foot (1.2 m) and 6 foot (1.8 m) levels. A simulated door frame made of nominal 1 inch by 4 inch (25 mm by 100 mm) pine was mounted behind the draperies. A schematic drawing of the burn room instrumentation is shown in Figure 1.

2.2.2 NFPA 701 Small-Scale Test

The NFPA 701 Small-Scale Test Method (as described in Chapter 3 of NFPA 701) was used to evaluate some of the fabrics which were examined by Belles and Beitel in their work at Southwest Research Institute [6]. The materials tested in that research were provided to the authors for examination in double layer configurations. The five fabrics used are identified in their report as follows:

Fabric	Weight, oz/yd^2	Weave	FR Treatment
FR polyester drapery	7.1	Plain	Inherent
Cotton drapery	8.4	Plain	Topical
FR polyester liner	3.1	Plain	Inherent
Cotton liner	4.1	Sateen	Topical
Polyester sheer	1.7	Plain	Topical

Each of these fabrics was tested as a single layer by NIST using the small-scale test to verify that they passed the NFPA 701 test criteria.

Four different testing modifications were employed by NIST for the evaluation of double layers of the Belles and Beitel materials. The samples were conditioned as required by the standard test method. The four test modifications utilized for NFPA 701 Small-Scale Testing were as follows:

- bottom ignition with a 12 second exposure to a 1½ inch flame (as specified in the standard);
- bottom ignition with a 12 second exposure and a 2 inch flame;
- bottom ignition with a 12 second exposure, a 1½ inch flame, and fabric layers sewn together at the bottom edge;
- bottom ignition with a 24 second exposure to a 1½ inch flame.

The last three modifications were chosen because each was considered to be more severe than the specified test conditions.

The authors decided not to utilize the small-scale NFPA 701 test for further work in this project because of the poor correlation with the Belles and Beitel full-scale results (see Section 3.2) and opted for the ASTM D 3659 Semi-Restraint Test and the NFPA 701 Large-Scale Test.

2.2.3 ASTM D 3659 Semi-Restraint Small-Scale Test

The ASTM Semi-Restraint Test is a small-scale test that measures the flame resistance of materials or fabrics (Figure 2). This test procedure was used in this study, but was varied for time of ignition and location of the ignition source. The seven sets of experiments were as follows:

- bottom ignition with a 6 second exposure;
- bottom ignition with a 12 second exposure;
- bottom ignition with a 24 second exposure;
- back-body ignition with a 6 second exposure;
- back-body ignition with a 12 second exposure;
- front-body ignition with a 6 second exposure; and
- front-body ignition with a 12 second exposure.

The experimentation followed the details of the test procedure but deviated in one detail; the average destroyed area was determined from the maximum char length multiplied by the maximum width of the char. While the maximum char length measures the degree of upward burning, the maximum width of the char provides a measure of the lateral burning and melting.

Two specimens, one drapery fabric and one lining fabric, were assembled on the support bar prior to conditioning and tested in the same manner as a single layer specimen specified by the test method. The specimens were placed over tenter pins at the top edge and allowed to hang freely. Two small butterfly clips were used to secure the specimens to the support bar because the specimens had a tendency to fall off of the bar. Two hairpin clips, one per side, were attached through both fabric layers in the lower corners of the specimen as specified by the standard. These clips were then attached to the side of the test cabinet. The clips served as a means to restrain some of the movement of the specimens as they attempt to avoid the flame of the ignition source.

The intent of the body ignition tests was to determine the interaction phenomenon of a thermoplastic adhering to a char-forming material. It is generally believed that this adhesion of two unlike materials could cause a sustained burn if sufficient heat is present to ignite the adhered area. The experiments that utilized body ignition in the Semi-Restraint Test Method required that the arm of the burner be swung towards the sample from the front of the cabinet, thus allowing the fan burner to be tangent and parallel to the sample, while placing the burner approximately two inches above the bottom edge of the sample (Figure 3). For front ignition, the drapery fabric faced the front door of the test cabinet, while for back ignition, the liner faced the front of the cabinet. A mirror was placed in the back of the test cabinet

to observe ignition (or non-ignition) of the fabric facing towards the back of the cabinet.

2.2.4 NFPA 701 Large-Scale Tests

The testing of the large-scale samples followed the protocol outlined by NPFA 701 Large-Scale (Chapter 6) for folded specimens. The materials were conditioned at 55% relative humidity, not the 25 to 50% specified in the standard.

The two layers of fabric, drapery fabric and liner, were assembled as a composite prior to conditioning. The drapery fabric was placed on top of the liner, and folded according to Section 6-2 of NFPA 701 Large-Scale Test. (The woven face of the blackout liner was visible on the back of the assembly; for the other five fabrics, face side of the fabric was not an important parameter.) The pleats of the mock-up drape were held in place during conditioning and testing by the use of butterfly clips, which simulated sewn pleats. The clips were placed approximately three inches from the top edge of the specimens. For testing, the support rod was inserted through the fabric layers and mounted in the 12 inch by 12 inch by seven foot (305 mm by 305 mm by 2.1 m) high test cabinet open at the bottom, as specified in the test procedure for the single layers.

The tests were run in a room, 10 feet 3 inches (3.1 m) wide by 10 feet 7 inches (3.2) deep having an 11 foot (3.4 m) high ceiling, with a variable exhaust system (Figure 4). The majority of experimental tests were run under conditions in which the cabinet door was open, the burn room door was closed, and the exhaust system turned off. Upon completion of the test, the exhaust system was activated in order to remove the combustion products from the room. Several tests were executed with the exhaust system turned on low, the burn room door open, and the cabinet door open. This was found to be unacceptable because of air current effects on the ignition source flame.

Two additional sets of tests were performed on the FR polyester/FR blackout fabric combination. The first set of experiments used a test configuration with the test cabinet door closed, the burn room door closed, and the exhaust system off. Secondly, another experiment examined the effects of not using the butterfly clips to hold the fabric layers in intimate contact in the test cabinet. These specimens were not clipped together during conditioning.

3. RESULTS AND DISCUSSION

3.1 FULL-SCALE EXPERIMENTS

A summary of the data obtained for the full-scale experiments is given in Table 1. The table provides the peak values and times to peak values for temperature in the room and rate of heat release, radiation on the wall behind the drapery assembly at the 1.2 m (4 foot) and 1.8 m (foot) levels, and smoke measurements in the stack. The temperatures in the room were not corrected for the burner output; the contribution of the burner was 75 to 80 °C above ambient. The measured heat release in the stack for each of the experiments was adjusted by subtracting the heat output from the burner (50 kW) throughout the 200 seconds of exposure. In addition, a rough visual estimate was made of the destroyed area by averaging the damage to the two fabric layers of the drapery combination; this is reported as average destroyed area (ADA).

3.1.1 Modacrylic Drapery fabric

Two experiments were conducted with the modacrylic drapery fabric: Test 1 with the blackout lining and Test 2 with the cotton lining. In Test 1, the peak rate of heat release was 365 kW at 77 seconds and the maximum temperature measured in the room was 327 °C at 53 seconds (Figure 5). The drapery burned to the ceiling and fell to the floor at about 47 seconds. The burner was extinguished at 205 seconds and all flaming ceased at about 220 seconds; however, the residue on the floor continued to smolder and produce smoke. The average destroyed area for this assembly was 100 percent.

Throughout Test 2, the drapery remained in place. The adjusted peak rate of heat release was 59 kW at 56 seconds and the maximum temperature measured in the room (10 inches below the ceiling - in all cases) was 189 °C at 40 seconds (Figure 5). All flaming ceased (exclusive of the burner) after about 115 seconds. The average destroyed area for this assembly was estimated to be 50 percent.

3.1.2 Wool Drapery Fabric

Two experiments were conducted with the wool drapery fabric: Test 3 with the cotton lining and Test 4 with the blackout lining. Throughout Test 3, the drapery remained in place. The peak rate of heat release was 103 kW at 40 seconds and the maximum temperature measured in the room was 159 °C at 40 seconds (Figure 6). Most burning had ceased at about 85 seconds and all flames were out at 116 seconds. The burner was extinguished at 204 seconds. The cotton liner was basically intact, although charred; the wool fabric was burned open in the center. The average destroyed area for this assembly was estimated to be 33 percent.

In Test 4, the peak rate of heat release was 210 kW at 160 seconds and the maximum temperature measured in the room was 230 °C at 160 seconds (Figure 6). The blackout lining showed extensive burning at about 12 seconds and pieces

began to fall to the floor at about 35 seconds. The flames were subsiding at about 63 seconds; however, there was continued burning on the right-center of the drapery. At about 132 seconds, the blackout became heavily involved and, at 160 seconds, the drapery fell to the floor. The burner was extinguished at 204 seconds and it was then apparent that the wood door frame was burning. The average destroyed area for this assembly was estimated to be 50 percent.

3.1.3 Polyester Drapery Fabric

Three experiments were conducted with the polyester drapery fabric: Tests 5 and 5A with the cotton lining and Test 6 with the blackout lining. Throughout Test 5, the drapery remained in place. The peak rate of heat release was only 7 kW at 88 seconds. The maximum temperature measured in the room was 108 °C at 188 seconds; however, the temperature plateaued at 68 seconds (105 °C) until 210 seconds (105 °C), never falling below 102 °C (Figure 7). The temperature began to drop when the burner was extinguished at 200 seconds. The average destroyed area for this assembly was estimated to be 33 percent Test 5A was conducted with the burner placed in the corner of the room at the left side seam of the undamaged drapery remaining from Test 5. The peak rate of heat release was 52 kW at 120 seconds and the maximum temperature measured in the room was 133 °C at 80 seconds. The temperature remained between 120 °C and 133 °C from 60 seconds to 203 seconds (Figure 7). The polyester began to fall away at 75 seconds with increased burning and large pieces were falling to the floor at about 100 seconds; however, burning subsided at about 130 seconds. The wood door frame was observed to be burning at about 185 seconds. The burner was extinguished at 200 seconds. The left side of the drapery was destroyed, accounting for another third of the drapery; burning ceased when it reached the damaged portion remaining from Test 5.

In Test 6, the peak rate of heat release was 227 kW at 170 seconds and the maximum temperature measured in the room was 209 °C at 170 seconds (Figure 7). The polyester fabric opened to the top at about 16 seconds and pulled aside at about 60 seconds. There was increased burning on the right side at 120 seconds and the blackout lining was heavily involved at about 145 seconds; at 170 seconds, there was considerable burning on the floor. The burner was extinguished at 205 seconds; continued burning was observed on the floor at 240 seconds. The average destroyed area for this assembly was estimated to be 75 percent.

3.1.4 Cotton Drapery Fabric

Three experiments were conducted with the cotton drapery fabric: Tests 7 and 7A with the cotton lining and Test 8 with the blackout lining. Throughout Tests 7 and 7A, the draperies remained in place. In Test 7, the peak rate of heat release was 28 kW at 128 seconds and the maximum temperature measured in the room was 105 °C at 198 seconds; however, the temperature remained between 95 °C and 105 °C from 58 seconds to 220 seconds (Figure 8). The drapery began to draw back at about 180 seconds. The burner was extinguished at 202 seconds and all flames were out at 203 seconds. The average destroyed area for this assembly was estimated to be 33 percent.

Test 7A was conducted with the burner placed in the corner of the room at the left side seam of the undamaged portion of the drapery remaining from Test 7. The peak rate of heat release was 25 kW at 160 seconds and the maximum temperature measured in the room was 144 °C at 160 seconds. The temperature remained between 140 °C and 144 °C from 110 seconds to 162 seconds (Figure 8). The drapery billowed at about 100 seconds. The cotton lining became involved at about 150 seconds and the whole left side fell to the floor at 160 seconds. The burner was extinguished at 202 seconds and all flames were out at 203 seconds. The left side of the drapery was destroyed, accounting for about one-third of the drapery; burning ceased when it reached the damaged portion remaining from Test 7.

In Test 8, the peak rate of heat release was 273 kW at 70 seconds and the maximum temperature measured in the room was 200 °C at 70 seconds (Figure 8). The blackout lining became involved at about 35 seconds and the drapery billowed at 40 seconds. Pieces were falling to the floor at about 56 seconds; however, the flames were subsiding at 70 seconds with continued burning on the floor. Large pieces of the drapery fell to the floor at about 116 seconds. The wood door frame was observed to be burning at about 180 seconds. The burner was extinguished at 202 seconds and all burning ceased at 270 seconds. About three-quarters of the cotton drapery was destroyed and all of the blackout liner was destroyed, for an average destroyed area of 88 percent.

3.2 NFPA 701 SMALL-SCALE TESTS

The summary of the results obtained for all of the Belles and Beitel fabric combinations tested in the NFPA 701 small-scale test apparatus (including the four modifications) is given in Table 2. Comparisons were made with the Belles and Beitel full-scale test results to determine whether the small-scale test could predict full-scale behavior as follows: if the results of the small-scale test combination failed the NFPA 701 criteria[4] and their report indicated that, for the same combination, flames reached the ceiling, then the small-test was considered to be predictive; conversely, if the small-scale test combination passed NFPA 701 and their report indicated that flames did not reach the ceiling, again the small-scale test would be predictive.

Of the 14 double layer combinations tested using the standard test method (12 second exposure to a 1½ inch flame), three failed the criteria for the small-scale NFPA 701 test procedure: polyester drapery/cotton drapery, polyester drapery/cotton liner, and cotton drapery/polyester liner. Applying the criteria for agreement stated above for those cases where comparable combinations were tested in full-scale, our data agreed in four of five cases with side seam drapery ignition and in only six of 10 cases when they used center drapery ignition.

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[4] The criteria used here are for single layers as described in NFPA 701 [2].

Of the 10 double layer combinations tested using the 12 second exposure with a two inch flame, only two failed the NFPA 701 test criteria: polyester drapery/cotton drapery and polyester drapery/cotton liner. Again, agreement with full-scale was reached in four of five cases using side ignition for the full-scale and in only five of 10 cases using center drapery ignition.

Of the 10 double layer combinations tested in the small-scale with the layers sewn together at the bottom (12 second exposure and 1½ inch flame), four combinations failed NFPA 701: polyester drapery/polyester drapery, polyester drapery/cotton drapery, polyester drapery/cotton liner, and cotton drapery/polyester liner. Agreement was reached in three of five cases for the full-scale using side seam ignition and in five of 10 cases for full-scale using center ignition.

Of the 10 double layer combinations tested in the small-scale using a 24 second exposure with a 1½ inch flame, only two combinations failed: polyester drapery/cotton drapery and polyester drapery/cotton liner. Again, agreement with full-scale was reached in four of five cases using side seam ignition and in only five of 10 cases using center ignition.

3.3 ASTM D 3659 SEMI-RESTRAINT TESTS

The ASTM D 3659 Semi-Restraint Test Method does not include pass/fail criteria to evaluate the performance of fabrics. Consequently, there is no means to compare easily the test results to standard criteria in order to determine whether or not any of the fabric combinations failed the test. None of the specimens burned their entire height of 15 inches, so there were no obvious failures.

Char lengths were measured for each of the individual fabrics in the double layer assembly. The reported average char length is the average of the three test specimens for one given generic fabric (e.g., modacrylic), not the average of the two types of fabrics used in the assembly (e.g., modacrylic and blackout liner). The average char lengths for each fabric layer and their corresponding standard deviation for the semi-restraint tests are given in Table 3. Table 3 also lists the other measured parameters of the experiments.

The results of these tests are shown in Figures 9 through 15. The results where the char lengths of the two fabric layers are most similar describe the most severe conditions (bottom ignition with the 12 second exposure - Figure 10). The six other ignition modifications do not exhibit this same characteristic. In the other ignition modifications (i.e., excluding the bottom ignition with a 12 second exposure), one of the fabrics had a substantially larger char length than its corresponding liner or drapery fabric. These differences in char lengths can be attributed to the location of the ignition source and the geometry of the test equipment.

3.3.1 Bottom ignition

The bottom ignition tests generally produced longer char lengths for the drapery fabric than for the liner (Figures 9 through 11). The longest char lengths for the drapery fabrics were obtained for the 24 second exposure, followed by the 12 second exposure and the 6 second exposure. The 12 second exposure tests, however, did produce the most similar char lengths between the drapery fabric and the liner. The 12 second bottom exposures produced longer char lengths for the blackout liner than for the cotton liner. Conversely, in the 6 second exposure tests, the cotton liner had longer char lengths than the blackout liner. For the 24 second exposure, the cotton liners had longer char lengths than the blackout liners in three out of four cases. One might expect the cotton fabric to have a longer char length than the blackout liner because of the differences in the areal densities between the fabrics, the cotton fabric being approximately one-third the weight of the blackout fabric. These two lining materials have different flame retardant chemistries which may manifest as differences in char lengths.

3.3.2 Body ignition

In the experiments utilizing back and front body ignition (Figures 12 through 15), the fabric surface that experienced the direct contact with the ignition source exhibited the longer char length. Generally, the fabric layer not in direct contact with the ignition source exhibited a very small char length, or no char at all. The sample in direct contact with the ignition source tended to protect it's mate or corresponding liner or drapery fabric from the flame. The expectation that dissimilar materials would adhere to each other and continue to burn was not seen in these experiments, although it was observed in earlier work [3-6]. The fan burner (see Figure 3) did not cause this adhesion to occur between the thermoplastic fabric and the char-forming fabric because of the burner's shape and location. The flame was placed parallel to the specimens, so the flame did not impinge normal to the specimens' surfaces. Use of different burners may result in different flammability behavior, such as the use of a small point-source ignition impinging on the specimen.

The results for the front body ignition tests showed longer char lengths for the 12 second exposure tests than for the 6 second exposure tests. The front body ignition tests for the wool and modacrylic fabrics (Figures 12 and 13) resulted in severe shrinkage when exposed to the ignition source. The shrinkage of the fabric produced a counter-force that pulled the two fabric samples away from the ignition source and, consequently, changed their configuration in the test cabinet. The test specimens were attached to the cabinet by loose chains and thus partially restrained movement of the fabric specimens. The restraining force caused the shrinking modacrylic or wool to remain in close proximity with the ignition source, while the mate or the lining fabric was repositioned farther from the ignition source or from the liner's original position in the cabinet. Conversely, the non-shrinking drapery material, i.e., cotton, resulted in longer char lengths for its lining fabrics than did the modacrylic and wool fabrics for their liners. The cotton and polyester fabrics are densely woven, thus being stiffer than the modacrylic and wool fabrics. The combination of being more rigid, i.e., polyester, or non-shrinking, i.e., cotton, kept the specimens in greater

contact with the ignition source. The polyester and cotton fabrics, however, exhibited shorter char lengths than the wool and modacrylic fabrics. The non-shrinking or densely woven characteristics of the drapery fabric probably kept the liners in closer contact to the ignition source and caused longer char lengths for the lining materials. The denser woven polyester and cotton fabrics may have absorbed and retained the heat better than the loosely woven wool and modacrylic fabrics, thus they might cause more radiation exposure to the lining fabrics and produce longer char lengths for the lining materials. As expected, the fabric in direct contact with the ignition source for the back body ignition tests (i.e., the lining fabrics) exhibited the longest char lengths (Figures 14 and 15). The longest char lengths were obtained for the drapery and liner fabrics with the 12 second exposure. In the 6 second exposure tests, the cotton liner produced longer char lengths than did the blackout liner, while in the 12 second exposure tests, the blackout and cotton liners had comparable char lengths.

3.4 NFPA 701 LARGE-SCALE TESTS

The results of the NFPA 701 Large-Scale tests are summarized in Table 4. Several procedural variants were utilized in the testing and are noted by superscripts next to the number of specimens tested. The number of test failures for the number of specimens tested, based on NFPA 701 test criteria, are also listed in Table 4.

Most of the data showed a very low degree of reproducibility, as shown by the huge standard deviation. This strongly suggests that one or more important variables were not held sufficiently constant during the series of tests. There may be within the fabrics themselves or in the test operation. This large scatter seriously limits the use of this method, in its present form, for predicting real-scale flammability. The following discussion captures some details and trends that might help further work and better stabilize the results.

The majority of the tests used a closed burn room door. This door was reopened at the two minute test mark in order to allow the experimenter to enter the room and extinguish the gas ignition source; fresh air entered the room at this point in the experiment. The exhaust hood was turned on when the specimen appeared to be extinguished.

The procedure that produced the longest char lengths for the fabrics were tests that used an open cabinet door, a closed burn room door, and no exhaust in the burn room (A tests). The closed burn-room door and the exhaust turned off were necessary to keep a steady, straight diffusion flame. Air currents in the room affected the ability of the flame to penetrate the specimens. This is apparent when comparing the A tests to the B tests; shorter char lengths were obtained for the B tests. In all test cases with conditions of an open cabinet door, a closed burn-room door, and the exhaust off, the blackout-lined specimens exhibited more severe ignition behavior than the specimens with the cotton liners. This closely resembles the full-scale fire behavior of the draperies tested. The rank order in the large-scale double

layer tests, based on average destroyed area, including the corresponding char lengths are as follows:

	average destroyed area	char length fabric/lining
modacrylic fabric/blackout lining	85%	80"/68"
polyester fabric/blackout lining	52%	47"/53"
wool fabric/blackout lining	48%	45"/46"
cotton fabric/blackout lining	44%	40"/43"
modacrylic fabric/cotton lining	44%	49"/45"
cotton fabric/cotton lining	40%	33"/37"
wool fabric/cotton lining	32%	28"/32"
polyester fabric/cotton lining	30%	25"/37"

The value for the average destroyed area of the double layer assembly is the average of the individual fabric destroyed areas. The polyester/cotton combination exhibits a relatively low average destroyed area, although the specimens failed two out of three times in the large-scale test because of sustained after-flaming.

The rank order for the average destroyed area is not the same as the rank order for char lengths. The average destroyed area rank order correlates much better to the performance of the full-scale drapery flammability tests (based on peak rate of heat release - see section 3.1) than the rank order of the char lengths.

3.4.1 Effect of Ventilation and Layer Separation on Test Results

As mentioned above, several of the large-scale tests were run under the following conditions: open cabinet door, open burn-room door, and exhaust hood on (B tests). The double layer specimens exhibited very small char lengths and average destroyed areas because the ignition flame had limited contact with the specimens due to air flow currents within the burn room.

The polyester drapery and blackout liner combination was tested under four test conditions to ascertain whether a closed cabinet door or separation between the layers might be more viable: A tests - open cabinet door, closed burn room door, and exhaust off; B tests - open cabinet door, open burn room door, and exhaust on; C tests - closed cabinet door (as specified in NFPA 701), closed burn room door, and exhaust off; and D tests - open cabinet door, closed burn room door, exhaust off, and separation between fabric layers.

One set of tests was utilized to compare the results of an open cabinet door (A tests) versus a closed cabinet door (C tests). The open cabinet door tests were more severe than the closed door tests because the former had longer char lengths, larger average destroyed areas, and longer after flame and after glow times.

Comparison of the tests with an open cabinet door, closed burn room door, and the exhaust off (A tests) between the tests under the same conditions except for separation between the layers of the assembly (D tests) exhibited more

severe ignition conditions for the former. The specimens with intimate contact (A tests) had longer char lengths (1.5 times), higher mass losses (25%), longer after flame times (9 times), shorter after glow times (16%), and larger average destroyed areas (1.25 times) than the specimens that had been separated. These results, however, do not provide the information necessary to quantify how the differences in the distances between the fabric layers affects the flammability characteristics of the double layer assemblies.

4. COMPARISON OF FULL-SCALE AND LABORATORY-SCALE TESTS

4.1 FULL-SCALE EXPERIMENTS

Examination of the data in Table 1 shows that peak rate of heat release (RHR) is one indicator of full-scale behavior of double layer drapery assemblies; the values ranged from 7 kW for the polyester/cotton combination to 365 kW for the modacrylic/blackout combination. However, an indicator of potential hazard from a burning drapery may be whether the flames reach the ceiling of the compartment. Therefore, the wool/cotton combination and each of the drapery combinations using the blackout liner would be considered to have a high hazard potential rating using this indicator.

This may be stated semi-quantitatively by considering the ratio of the peak rate of heat release to the estimated average destroyed area. The following table shows the ranking based on this ratio for those fabric combinations which were exposed to center ignition.

	RHR	% ADA	Flames to Ceiling	RHR/% ADA
Wool/Blackout	210	50	Yes	4
Modacrylic/Blackout	365	100	Yes	4
Wool/Cotton	103	33	Yes	3
Cotton/Blackout	273	88	Yes	3
Polyester/Blackout	227	75	Yes	3
Modacrylic/Cotton	59	50	No	1
Cotton/Cotton	23	33	No	1
Polyester/Cotton	7	33	No	0.2

As can be seen from the above, there is a definite difference in the ratio between those combinations which burned to the ceiling and those which did not. Although the wool/cotton combination had an intermediate peak rate of heat release, the average destroyed area was low, resulting in a high RHR/% ADA. This high ratio is consistent with the observation that flames reached the ceiling. Therefore, the first five combinations could be considered to be failures. This assumption is the basis for the further analysis of the small-scale semi-restraint data and for the large-scale NFPA 701 test results.

Although room temperature profiles, radiation behind the drapery, and smoke density in the exhaust stack were measured during the course of the experiments, these data were not used in the comparisons to follow.

4.2 SEMI-RESTRAINT TESTS

Each of the modifications used with the semi-restraint test are treated separately in the following discussion. These include: bottom ignition with 6, 12, and 24 second exposure; back body ignition with 6 and 12 second exposure; and front body ignition with 6 and 12 second exposure. For this analysis, from the data in Table 3, the average char length for the two layers and the measurement of after flame and flame drip are used to make comparisons with the results of the full-scale experiments. A fabric combination is considered to be a failure if the char length exceeds a maximum value or if any of the tests exhibited after flame (AF) or flame drip (FD) or both (AF/FD). This provides a basis for determining whether the small-scale test could be used to predict full-scale behavior. In all the cases discussed below, the selection of pass/failure criteria is truly arbitrary. Therefore, the chance of them working for other fabric combinations is not high.

It should be noted that flame drip was observed only for the polyester/cotton and polyester/blackout combinations.

4.2.1 Bottom Ignition - 6 Second Exposure

The average char lengths (for the two layers) ranged from 1.75 inches for the cotton/blackout combination to 4.20 inches for the wool/cotton combination. In addition, seven of the eight assemblies exhibited after flame (AF) or flame drip (FD) or both (AF/FD). The following shows the extent of agreement between these results and the results of the full-scale experiments.

Assuming a given acceptable average char length, and whether or not there is after flame and/or flame drip, the number of agreements is shown as a fraction of the total number of comparisons.

Max acceptable char length, in	Char only	Char + AF/FD
1.0	5/8	5/8
2.0	4/8	5/8
3.0	3/8	5/8
4.0	4/8	6/8
5.0	3/8	6/8

This summary shows that, at best, only six of the eight small-scale test combinations would predict the full-scale fire behavior.

4.2.2 Bottom Ignition - 12 Second Exposure

The average char lengths (for the two layers) ranged from 3.40 inches for the modacrylic/blackout combination to 7.90 inches for the wool/blackout combination. In addition, four of the eight assemblies exhibited after flame or flame drip or both. The following shows the extent of agreement between these results and the results of the full-scale experiments.

Max acceptable char length, in	Char only	Char + AF/FD
3.0	5/8	5/8
4.0	4/8	5/8
5.0	4/8	6/8
6.0	4/8	5/8
7.0	4/8	5/8
8.0	3/8	5/8

Again, this summary shows that, at best, only six of the eight small-scale test combinations would predict the full-scale fire behavior.

4.2.3 Bottom Ignition - 24 Second Exposure

The average char lengths (for the two layers) ranged from 3.45 inches for the modacrylic/blackout combination to 5.80 inches for the cotton/cotton combination. In addition, four of the eight assemblies exhibited after flame or flame drip or both. The following shows the extent of agreement between these results and the results of the full-scale experiments.

Max acceptable char length, in	Char only	Char + AF/FD
3.0	5/8	5/8
4.0	4/8	2/8
5.0	3/8	2/8
6.0	3/8	3/8

This summary shows that, at best, only five of the eight small-scale test combinations would predict the full-scale fire behavior.

4.2.4 Back Body Ignition - 6 Second Exposure

The average char lengths (for the two layers) ranged from 1.35 inches for the cotton/blackout combination to 4.20 inches for the wool/cotton combination. Only one of the eight assemblies exhibited after flame (wool/blackout).

The following shows the extent of agreement between these results and the results of the full-scale experiments.

Max acceptable char length, in	Char only	Char + AF/FD
1.0	5/8	5/8
2.0	1/8	2/8
3.0	2/8	3/8
4.0	3/8	4/8
5.0	3/8	4/8

This summary shows that, at best, only five of the eight small-scale test combinations would predict the full-scale behavior.

4.2.5 Back Body Ignition - 12 Second Exposure

The average char length (for the two layers) ranged from 2.70 inches for the modacrylic/blackout combination to 5.25 inches for the polyester/cotton combination. In addition, three of the eight assemblies exhibited after flame. The following shows the extent of agreement between these results and the results of the full-scale experiments.

Max acceptable char length, in	Char only	Char + AF/FD
2.0	5/8	5/8
3.0	3/8	4/8
4.0	1/8	4/8
5.0	2/8	5/8
6.0	3/8	6/8

This summary shows that, if char length of at least 6.0 inches is acceptable and only after flame and flame drip were cause for failure, then six of the eight small-scale test combinations would predict the full-scale behavior. An acceptable maximum char length of up to 6.0 inches, with no after flame permitted, provides the best predictive capability for full-scale behavior for the materials tested using the semi-restraint test concept.

4.2.6 Front Body Ignition - 6 Second Exposure

The average char length (for the two layers) ranged from 1.95 inches for the polyester/cotton combination to 3.50 inches for the cotton/cotton and the cotton/blackout combinations. In addition, three of the eight assemblies exhibited after flame or flame drip.

The following shows the extent of agreement between these results and the results of the full-scale experiments.

Max acceptable char length, in	Char only	Char + AF/FD
1.0	5/8	5/8
2.0	6/8	5/8
3.0	3/8	2/8
4.0	3/8	2/8

This summary shows that, at best, six of the eight small-scale test combinations would predict the full-scale behavior.

4.2.7 Front Body Ignition - 12 Second Exposure

The average char length (for the two layers) ranged from 3.20 inches for the modacrylic/blackout and cotton/blackout combinations to 4.75 inches for the polyester/cotton combination. In addition, five of the eight assemblies exhibited after flame or flame drip or both. The following shows the extent of agreement between these results and the results of the full-scale experiments.

Max acceptable char length, in	Char only	Char + AF/FD
3.0	5/8	5/8
4.0	2/8	3/8
5.0	3/8	4/8

This summary shows that no more than five of the eight small-scale test combinations would predict the full-scale behavior.

4.3 NFPA 701 LARGE-SCALE TESTS

Applying the acceptance criteria given in NFPA 701 (maximum 42 inch char length, maximum 2 second after flame, and no flame drip), and comparing these results to the acceptance criterion for the full-scale behavior (Section 4.1), only five of the eight large-scale test combinations would predict the full-scale fire behavior. If 42 inch maximum char length was the only criterion, then agreement would be increased to six of eight; however, flame drip and/or after flame for the polyester fabric combinations (varying up to 102 seconds) should not be ignored.

Adding a requirement for maximum average destroyed area of 800 square inches for the two layers to those of NFPA 701 would give agreement for six of eight combinations. A maximum weight loss requirement of 15 percent for the assembly added to the NPFA 701 requirements also gave agreement for six of the eight combinations.

If after flame and flame drip are not considered, and reducing the maximum allowable average char length for the two layers to 40 inches or using a

maximum average destroyed area criterion of 800 square inches, agreement is obtained for six of eight combinations. If only average destroyed area (maximum 800 square inches) and a maximum average after flame requirement of 10 seconds are considered, then agreement is reached in only five of eight cases. However, the wide spread in average destroyed area and after flame times negate the use of these criteria. Again, in the interest of safety, after flame and/or flame drip requirements should be included.

Only one series of tests (polyester fabric/blackout liner) was performed with the large-scale test cabinet door closed, as specified in NFPA 701 (C tests). It appeared that the closed door did not provide enough air within the cabinet for complete combustion. The increased fuel load in the cabinet may have restricted the flow of air from the bottom, resulting in slower burning of the multiple layer assembly. The closed cabinet door may be an appropriate test for single layer fabrics, but multiple layer assemblies have approximately twice the fuel load of single layer specimens, thereby requiring more air for burning. As noted in section 4.3, the open cabinet door tests were more severe than the closed door tests, as evidenced by longer char lengths, longer after flame times, and longer after glow times (see Table 4).

Despite the large variance in average destroyed area in the large-scale tests, a comparison was made between the average destroyed area in the full-scale experiments (center ignition only) and the average destroyed area in the large-scale tests using the A conditions (open cabinet door, closed burn-room door, and the exhaust system off). As can be seen in Figure 16, only one fabric combination (cotton/blackout) was an outlier; the correlation factor was 0.82. Eliminating the cotton/blackout combination increases the correlation factor to 0.95 (Figure 17).

In addition, a comparison was made between the peak rate of heat release in the full-scale experiments (center ignition only) and the average destroyed area in the large-scale tests using the A conditions; the correlation factor was only 0.81 (Figure 18).

These comparisons were made using average values for the destroyed areas; however, because the range of values is large, particularly for the large-scale tests, the correlations may be meaningless.

5. CONCLUSIONS

From the data, there is no simple solution, although there are some primary leads. The physics is complex and the correlation approach is risky since only a limited number of fabric combinations were examined. Based on the present research, the following conclusions can be made:

1. The NFPA 701 Small-Scale Test adapted to a double layer configuration does not predict the full-scale behavior of multiple layer drapery assemblies.

2. The ASTM D 3659 Semi-Restraint Test Method, as it is currently written, does not predict the full-scale flammability behavior of multiple layer drapery assemblies. However, with further development of this method, a limited correlation might be possible.

3. The NFPA 701 Large-Scale Test offers at best a limited correlation for predicting the full-scale flammability behavior of multiple layer drapery assemblies. Because of the random behavior of many fabric combinations, these correlations should only be used to guide further work.

4. For the specific drapery fabric and lining material combinations examined in this study, those with the present blackout liner burned most severely.

5. In full-scale multiple layer drapery experiments, ignition of the side seam, where the two panels of fabric are sewn together vertically, appears to result in more severe burns than center ignition.

6. Based on the results of this limited study, it is too early to recommend any test protocol for assessing the fire performance of multiple layer drapery assemblies for inclusion in NFPA 701.

Combined fabric weight of the assembly appears to have a significant effect on the rate of heat release determined in full-scale experiments. Although the wool/cotton assembly performed poorly in the full-scale and resulted in a moderate rate of heat release, its performance in the NFPA 701 Large-Scale Test was good. Burning of the high fabric weight combinations in the large-scale test is inhibited by the limited air supply in the test stack.

6. RECOMMENDATIONS

Although the results of this study have been informative, there needs to be additional work in order to accomplish the original objectives. Consideration should be given to those parameters which the existing tests do not address; for example, rate of heat release of the multiple layer assembly, the effect of external radiation on the burning, and geometry of the specimen. Several of the following recommendations may lead to an improved laboratory-scale test procedure for predicting the fire performance of multiple layer drapery assemblies in the real world environment, while others are specific for improving currently accepted test methods adapted for this application.

1. The scope of the multiple layer drapery study should be broadened to include other fabrics and combinations. Fabric weights and constructions, other than those used in this study, should be considered.

2. The scope of the multiple layer drapery problem should be broadened to include multiple track systems in order to develop installation guidelines. The spacing between two tracks would be varied and burning would be performed in an open draft-free environment.

3. Improvements in the semi-restraint test method concept are needed to better define the use of this method. Some suggested modifications, used alone or in combination, to the method are as follows:

   - Evaluate the use of body ignition with either a diffusion flame or premixed flame applied perpendicular to the face of the fabric assembly.
   - Use folded or flat fabric assemblies using larger fabric samples to determine whether the specimens self-extinguish or continue to burn.
   - Support the fabric assemblies in an open draft-free environment to ensure that the specimens do not self-extinguish due to a vitiated atmosphere. No confining test cabinet would be required.
   - Consider the use of an external radiant energy source to enhance burning.
   - Consider using heat evolution criteria to evaluate the performance of the composite assemblies.

4. Improvements in the large-scale test method are needed to further develop the use of this method. Some suggested modifications, used alone or in combination, to the method are as follows:

   - Further explore the open door procedure (or remove the door) using the existing seven foot stack.
   - Construct the stack of a low thermal conductivity material (e.g., calcium silicate board rather than sheet metal) in order to reduce the heat losses through the stack walls.
   - Use a shorter specimen in order to reduce the amount of fabric needed for each test. This also suggests the use of a shorter stack.
   - Increase the stack dimensions from one foot on each side to two feet on a side to provide for improved air circulation.
   - Install a thermocouple grid at the top of the stack in order to obtain an estimate of heat release.
   - Measure rate of heat release by ducting the bottom of the enclosed stack and measuring air flow (Textile Research Institute approach [12,13]).

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Table 1. Full-Scale Experiments

Test no.	Materials - Drapery - Liner	Flames to Ceiling	Maximum Temp. in Room, °C	Peak Rate of Heat Release, kW	Peak Radiation, kW/m^2 1.2m	Peak Radiation, kW/m^2 1.8m	Peak Smoke, OD/m	Estimated Average Destroyed Area (ADA), %	RHR/% ADA
2	Modacrylic Cotton Liner	No	189 (40)*	59 (56)*	1.4	2.5	9.2	50	1
1	Modacrylic Blackout Liner	Yes	327 (53)	365 (77)	6.7	5.3	9.6	100	4
3	Wool Cotton Liner	Yes	159 (40)	103 (40)	3.4	1.2	6.1	33	3
4	Wool Blackout Liner	Yes	230 (160)	210 (160)	2.2	2.1	10.2	50	4
5	Polyester Cotton Liner	No	108 (188)	7 (88)	2.3	1.0	3.9	33	0.2
5A	Polyester Cotton Liner	No	133 (80)	52 (120)	NA**	NA	7.0	NA	NA
6	Polyester Blackout Liner	Yes	209 (170)	227 (170)	3.4	2.4	9.4	75	3
7	Cotton Cotton Liner	No	105 (198)	23 (128)	1.7	1.4	5.7	33	1
7A	Cotton Cotton Liner	No	144 (160)	25 (160)	NA	NA	4.8	NA	NA
8	Cotton Blackout Liner	Yes	200 (70)	273 (70)	4.1	2.8	9.3	88	3

* Number in ( ) is time to peak in seconds

** Not applicable, since there were no radiometers behind the drapery where side ignition was used.

Table 2. Results of Small-Scale NFPA 701 Tests of Materials Tested by Belles & Beitel

Materials - Drapery - Liner	Number of Specimens	Exposure (sec.)	Place of Ignition	Char Length ± S.D. (inches)	Mass Loss ± S.D. (grams)	After Flame ± S.D. (sec.)	After Glow ± S.D. (sec.)	Flame Drip # ± S.D. [sec ± S.D.]
Polyester Drape	3	12	Bottom	4.3 ± 0.3	0.1 ± 0.0	0 ± 0	0 ± 0	0 ± 0
Cotton Drape	3	12	Bottom	2.7 ± 0.2	0.0 ± 0.0	0 ± 0	0.5 ± 0.0	0 ± 0
Polyester Liner	3	12	Bottom	4.9 ± 0.5	0.0 ± 0.0	0 ± 0	0 ± 0	0 ± 0
Cotton Liner	3	12	Bottom	4.4 ± 0.3	0.0 ± 0.0	0 ± 0	0.7 ± 0.3	0 ± 0
Polyester Sheer	3	12	Bottom	5.3 ± 0.8	0.0 ± 0.0	0 ± 0	0 ± 0	0 ± 0
Polyester Drape Polyester Drape	3	12	Bottom	3.3 ± 0.1 3.3 ± 0.1	0.0 ± 0.0	0 ± 0	0 ± 0	0 ± 0
Polyester Drape Cotton Drape	3^F	12	Bottom	2.4 ± 0.3 2.4 ± 0.3	0.0 ± 0.0	16.0 ± 13.9	0.3 ± 0.6	0 ± 0
Polyester Drape Polyester Liner	3	12	Bottom	3.4 ± 0.1 3.4 ± 0.1	0.0 ± 0.0	0 ± 0	0 ± 0	0 ± 0
Polyester Drape Cotton Liner	3^F	12	Bottom	4.2 ± 1.8 4.3 ± 1.9	0.1 ± 0.1	25.0 ± 20.8	0 ± 0	0 ± 0
Polyester Liner Polyester Sheer	3	12	Bottom	3.4 ± 0.4 3.8 ± 0.3	0.0 ± 0.0	0 ± 0	0 ± 0	0 ± 0
Cotton Drape Cotton Drape	3	12	Bottom	2.7 ± 0.2 2.7 ± 0.2	0.0 ± 0.0	0 ± 0	1.7 ± 0.8	0 ± 0
Cotton Drape Polyester Liner	3^F	12	Bottom	2.8 ± 0.2 3.4 ± 0.4	0.0 ± 0.0	2.3 ± 4.0	0.7 ± 0.6	0 ± 0
Cotton Drape Cotton Liner	3	12	Bottom	2.7 ± 0.3 2.6 ± 0.1	0.0 ± 0.0	0 ± 0	1.3 ± 0.4	0 ± 0
Cotton Drape Polyester Sheer	3	12	Bottom	2.7 ± 0.1 3.2 ± 0.3	0.0 ± 0.0	0 ± 0	0.8 ± 0.3	0 ± 0
Polyester Liner Polyester Liner	3	12	Bottom	4.3 ± 0.6 4.3 ± 0.6	0.0 ± 0.0	0 ± 0	0 ± 0	0 ± 0
Polyester Liner Cotton Liner	3	12	Bottom	4.3 ± 0.3 3.9 ± 0.1	0.0 ± 0.0	0 ± 0	0.4 ± 0.1	0 ± 0

Table 2. Results of Small-Scale NFPA 701 Tests of Materials Tested by Belles & Beitel (cont'd.)

Materials - Drapery - Liner	Number of Specimens	Exposure (sec.)	Place of Ignition	Char Length ± S.D. (inches)	Mass Loss ± S.D. (grams)	After Flame ± S.D. (sec.)	After Glow ± S.D. (sec.)	Flame Drip # ± S.D. [sec ± S.D.]
Polyester Liner Polyester Sheer	3	12	Bottom	4.6 ± 0.5 4.6 ± 0.5	0.0 ± 0.0	0 ± 0	0 ± 0	0 ± 0
Cotton Liner Cotton Liner	3	12	Bottom	4.0 ± 0.3 4.0 ± 0.3	0.1 ± 0.0	0 ± 0	0.8 ± 0.3	0 ± 0
Cotton Liner Polyester Sheer	3	12	Bottom	4.3 ± 0.5 4.8 ± 1.3	0.0 ± 0.0	1.0 ± 1.7	0.7 ± 0.3	0 ± 0
Polyester Drape Polyester Drape	2^{A}	12	Bottom	3.3 ± 0.0 3.3 ± 0.0	NM	0 ± 0	0 ± 0	0 ± 0
Polyester Drape Cotton Drape	5^{AF}	12	Bottom	3.7 ± 0.1 3.4 ± 0.4	NM	14.4 ± 18.1	0.4 ± 0.5	0.3 ± 0.5
Polyester Drape Polyester Liner	2^{A}	12	Bottom	4.3 ± 0.1 4.8 ± 0.0	NM	0 ± 0	0 ± 0	0 ± 0
Polyester Drape Cotton Liner	5^{AF}	12	Bottom	5.6 ± 3.0 5.3 ± 2.8	NM	31.2 ± 26.7	0 ± 0	0 ± 0
Cotton Drape Cotton Drape	5^{A}	12	Bottom	3.0 ± 0.3 3.0 ± 0.4	NM	0 ± 0	0.9 ± 0.2	0 ± 0
Cotton Drape Polyester Liner	5^{A}	12	Bottom	3.4 ± 0.3 3.5 ± 0.5	NM	0 ± 0	1.0 ± 0.0	0 ± 0
Cotton Drape Cotton Liner	5^{A}	12	Bottom	3.3 ± 0.5 3.1 ± 0.5	NM	0 ± 0	1.0 ± 0.0	0 ± 0
Polyester Liner Polyester Liner	2^{A}	12	Bottom	4.1 ± 0.1 4.1 ± 0.1	NM	0 ± 0	0 ± 0	0 ± 0
Polyester Liner Cotton Liner	5^{A}	12	Bottom	4.6 ± 0.3 4.2 ± 0.3	NM	0.6 ± 1.3	0.3 ± 0.5	0 ± 0
Cotton Liner Cotton Liner	5^{A}	12	Bottom	4.2 ± 0.4 4.1 ± 0.6	NM	0 ± 0	0.7 ± 0.6	0 ± 0
Polyester Drape Polyester Drape	2^{BF}	12	Bottom	3.4 ± 0.1 3.4 ± 0.1	NM	13.5 ± 6.4	0 ± 0	0.5 ± 0.7

Table 2. Results of Small-Scale NFPA 701 Tests of Materials Tested by Belles & Beitel (cont'd.)

Materials - Drapery - Liner	Number of Specimens	Exposure (sec.)	Place of Ignition	Char Length ± S.D. (inches)	Mass Loss ± S.D. (grams)	After Flame ± S.D. (sec.)	After Glow ± S.D. (sec.)	Flame Drip # ± S.D. [sec ± S.D.]
Polyester Drape Cotton Drape	5^{BF}	12	Bottom	6.7 ± 0.3 6.6 ± 3.0	NM	79.8 ± 44.8	2.4 ± 2.5	0.2 ± 0.5
Polyester Drape Polyester Liner	2^{B}	12	Bottom	3.7 ± 0.3 4.0 ± 0.4	NM	1.3 ± 1.8	0 ± 0	0.5 ± 0.7
Polyester Drape Cotton Liner	5^{BF}	12	Bottom	7.2 ± 2.0 7.1 ± 2.1	NM	56.0 ± 47.6	0.8 ± 1.1	0.3 ± 0.5
Cotton Drape Cotton Drape	5^{B}	12	Bottom	3.0 ± 0.3 3.0 ± 0.3	NM	1.1 ± 0.7	0 ± 0	0 ± 0
Cotton Drape Polyester Liner	5^{BF}	12	Bottom	4.3 ± 0.3 5.0 ± 0.5	NM	2.0 ± 2.8	0.9 ± 0.2	0 ± 0
Cotton Drape Cotton Liner	5^{B}	12	Bottom	3.6 ± 0.2 3.5 ± 0.2	NM	0 ± 0	2.0 ± 0.4	0 ± 0
Polyester Liner Polyester Liner	2^{B}	12	Bottom	3.8 ± 0.2 3.8 ± 0.2	NM	0 ± 0	0 ± 0	0 ± 0
Polyester Liner Cotton Liner	5^{B}	12	Bottom	5.0 ± 0.6 4.8 ± [illegible]5	NM	1.4 ± 2.6	1.1 ± 0.2	0 ± 0
Cotton Liner Cotton Liner	5^{B}	12	Bottom	4.2 ± 0.2 4.1 ± 0.2	NM	0 ± 0	1.2 ± 0.3	0 ± 0
Polyester Drape Polyester Drape	2	24	Bottom	4.3 ± 0.1 4.1 ± 0.1	NM	0 ± 0	0 ± 0	0 ± 0
Polyester Drape Cotton Drape	5^{F}	24	Bottom	6.4 ± 3.3 6.3 ± 3.4	NM	27.7 ± 38.0	0.8 ± 0.8	0 ± 0
Polyester Drape Polyester Liner	2	24	Bottom	4.0 ± 0.4 4.1 ± 0.3	NM	0 ± 0	0 ± 0	0 ± 0
Polyester Drape Cotton Liner	5^{F}	24	Bottom	6.2 ± 2.8 6.1 ± 2.5	NM	27.0 ± 19.5	0 ± 0	0 ± 0
Cotton Drape Cotton Drape	5	24	Bottom	4.0 ± 0.3 4.0 ± 0.2	NM	0 ± 0	1.8 ± 0.3	0 ± 0

Table 2. Results of Small-Scale NFPA 701 Tests of Materials Tested by Belles & Beitel (cont'd.)

Materials - Drapery - Liner	Number of Specimens	Exposure (sec.)	Place of Ignition	Char Length ± S.D. (inches)	Mass Loss ± S.D. (grams)	After Flame ± S.D. (sec.)	After Glow ± S.D. (sec.)	Flame Drip # ± S.D. [sec ± S.D.]
Cotton Drape Polyester Liner	5	24	Bottom	4.3 ± 0.3 4.8 ± 0.8	NM	0 ± 0	1.4 ± 0.3	0 ± 0
Cotton Drape Cotton Liner	5	24	Bottom	4.1 ± 0.1 3.9 ± 0.2	NM	0 ± 0	1.3 ± 0.5	0 ± 0
Polyester Liner Polyester Liner	2	24	Bottom	5.0 ± 0.6 5.0 ± 0.6	NM	0 ± 0	0 ± 0	0 ± 0
Polyester Liner Cotton Liner	5	24	Bottom	4.9 ± 0.8 5.1 ± 1.0	NM	0 ± 0	0.8 ± 0.2	0 ± 0
Cotton Liner Cotton Liner	5	24	Bottom	4.5 ± 0.2 4.5 ± 0.2	NM	0 ± 0	0.9 ± 0.1	0 ± 0

* - Standard Deviation (S.D.)
A - Specimens are tested with a 2-inch ignition flame, not the standard 1.5-inch flame.
B - Specimens are sewn together with a cotton thread set at 14 stitches per inch. The stitching is placed parallel to the 6-inch width of the specimen, and located 3/8" from the edge. The sewn edge is placed into the ignition flame for testing.
F - Average value of the tests would constitute a failure based on NFPA 701 criteria for char length and/or afterflame.
NM - Not Measured

Table 3. Results of Small-Scale Semi-Restraint Tests

Materials - Drapery - Liner	Number of Specimens	Exposure (sec.)	Place of Ignition	Char Length ± S.D. (inches)	Mass Loss ± S.D. (%)	After Flame ± S.D. (sec.)	After Glow ± S.D. (sec.)	Flame Drip # ± S.D. [sec ± S.D.]	Destroyed Area ± S.D. (sq. inches)
Modacrylic Cotton Liner	3	6	Bottom	3.6 ± 0.4 1.6 ± 2.1	0.4 ± 0.3	0.3 ± 0.3	0 ± 0	0 ± 0	4.3 ± 1.5 1.5 ± 2.2
Modacrylic Cotton Liner	3	12	Bottom	4.5 ± 0.5 2.8 ± 2.1	0.6 ± 0.1	0 ± 0	0 ± 0	0 ± 0	7.6 ± 2.1 1.7 ± 2.0
Modacrylic Cotton Liner	3	24	Bottom	5.0 ± 1.3 2.5 ± 1.2	1.8 ± 1.3	0 ± 0	0 ± 0	0 ± 0	8.6 ± 3.8 2.4 ± 1.3
Modacrylic Cotton Liner	3	6	Back	2.3 ± 0.8 4.8 ± 0.9	0.1 ± 0.9	0 ± 0	0 ± 0	0 ± 0	3.4 ± 2.3 7.3 ± 2.6
Modacrylic Cotton Liner	3	12	Back	3.2 ± 1.5 6.5 ± 0.5	1.7 ± 0.4	0 ± 0	0 ± 0	0 ± 0	3.8 ± 1.7 11.4 ± 2.3
Modacrylic Cotton Liner	3	6	Front	5.1 ± 0.4 0.3 ± 0.6	0.1 ± 0.1	0.2 ± 0.3	0 ± 0	0 ± 0	8.1 ± 2.5 0.3 ± 0.4
Modacrylic Cotton Liner	3	12	Front	6.5 ± 0.9 0 ± 0	0.7 ± 0.5	0.4 ± 0.5	0 ± 0	0 ± 0	21.0 ± 2.6 0 ± 0
Modacrylic Blackout Liner	3	6	Bottom	4.8 ± 0.6 0.5 ± 0.3	0.1 ± 0.1	0.8 ± 1.0	0 ± 0	0 ± 0	5.4 ± 1.2 0.3 ± 0.2
Modacrylic Blackout Liner	3	12	Bottom	3.5 ± 1.5 3.3 ± 2.9	5.2 ± 6.7	0 ± 0	15.6 ± 14.6	0 ± 0	5.5 ± 3.0 5.9 ± 5.4
Modacrylic Blackout Liner	3	24	Bottom	6.8 ± 2.8 0.1 ± 0.1	0.7 ± 2.1	2.0 ± 3.5	0 ± 0	0 ± 0	14.3 ± 9.2 0.0 ± 0.0
Modacrylic Blackout Liner	3	6	Back	0.3 ± 0.3 3.0 ± 0.2	0.5 ± 0.7	0 ± 0	0 ± 0	0 ± 0	0.1 ± 0.1 3.2 ± 0.1
Modacrylic Blackout Liner	3	12	Back	0.2 ± 0.3 5.2 ± 0.3	0.5 ± 0.4	0.3 ± 0.6	0 ± 0	0 ± 0	0.1 ± 0.2 7.3 ± 0.4
Modacrylic Blackout Liner	3	6	Front	4.8 ± 0.3 0 ± 0	0.2 ± 0.2	0 ± 0	0 ± 0	0 ± 0	12.7 ± 2.0 0 ± 0
Modacrylic Blackout Liner	3	12	Front	5.9 ± 0.9 0.5 ± 0.5	0.2 ± 0.1	0 ± 0	0 ± 0	0 ± 0	19.9 ± 5.2 0.3 ± 0.3

Table 3. Results of Small-Scale Semi-Restraint Tests (cont'd.)

Materials - Drapery - Liner	Number of Specimens	Exposure (sec.)	Place of Ignition	Char Length ± S.D. (inches)	Mass Loss ± S.D. (%)	After Flame ± S.D. (sec.)	After Glow ± S.D. (sec.)	Flame Drip # ± S.D. [sec ± S.D.]	Destroyed Area ± S.D. (sq. inches)
Polyester Cotton Liner	3	6	Bottom	2.3 ± 0.8 5.5 ± 0.0	0.6 ± 0.2	0 ± 0	0.4 ± 0.1	0.3 ± 0.6 [1.0 ± 0.0]	1.3 ± 0.3 6.4 ± 1.6
Polyester Cotton Liner	3	12	Bottom	6.0 ± 5.8 5.2 ± 1.4	0.6 ± 0.3	3.7 ± 6.4	1.7 ± 2.1	1.0 ± 1.0 [0.8 ± 0.5]	3.3 ± 2.6 3.8 ± 1.3
Polyester Cotton Liner	3	24	Bottom	4.6 ± 1.7 3.7 ± 2.6	0.7 ± 0.4	2.0 ± 3.5	0.2 ± 0.1	2.0 ± 1.0 [1.0 ± 0.0]	5.0 ± 0.9 4.7 ± 5.8
Polyester Cotton Liner	3	6	Back	2.4 ± 1.9 5.8 ± 0.3	1.4 ± 1.1	0 ± 0	0 ± 0	0 ± 0	3.5 ± 4.8 9.6 ± 1.7
Polyester Cotton Liner	3	12	Back	3.8 ± 1.0 6.7 ± 0.3	1.3 ± 0.1	0 ± 0	0 ± 0	0 ± 0	5.2 ± 2.1 11.3 ± 0.8
Polyester Cotton Liner	3	6	Front	2.7 ± 0.8 1.2 ± 1.0	0.7 ± 0.1	0 ± 0	0 ± 0	0.7 ± 0.6 [1.0 ± 0.0]	3.3 ± 0.7 0.7 ± 0.6
Polyester Cotton Liner	3	12	Front	3.7 ± 0.6 5.8 ± 1.4	4.6 ± 5.4	0.2 ± 0.3	0 ± 0	1.7 ± 1.2 [1.0 ± 0.0]	4.6 ± 0.7 7.1 ± 1.3
Polyester Blackout Liner	3	6	Bottom	3.8 ± 0.6 0.9 ± 1.4	0.1 ± 0.1	0.2 ± 0.3	4.7 ± 8.1	0.7 ± 0.6 [1.0 ± 0.0]	2.6 ± 0.9 0.4 ± 0.7
Polyester Blackout Liner	3	12	Bottom	4.3 ± 0.2 3.7 ± 3.2	1.3 ± 0.4	0 ± 0	13.0 ± 11.5	3.0 ± 1.0 [1.0 ± 0.0]	3.9 ± 0.5 4.1 ± 3.7
Polyester Blackout Liner	3	24	Bottom	5.2 ± 3.0 4.7 ± 4.2	0.8 ± 0.6	0 ± 0	19.0 ± 18.1	1.0 ± 1.0 [1.0 ± 1.0]	5.6 ± 4.4 6.5 ± 6.1
Polyester Blackout Liner	3	6	Back	0 ± 0 3.0 ± 0.3	0.0 ± 0.0	0 ± 0	0 ± 0	0 ± 0	0 ± 0 3.2 ± 0.3
Polyester Blackout Liner	3	12	Back	1.1 ± 1.6 5.6 ± 0.6	0.3 ± 0.2	0.5 ± 0.5	1.7 ± 2.9	0 ± 0	0.4 ± 0.4 8.1 ± 1.1
Polyester Blackout Liner	3	6	Front	4.4 ± 0.1 0.1 ± 0.1	0.5 ± 2.5	0 ± 0	0 ± 0	1.3 ± 0.6 [1.0 ± 1.0]	5.0 ± 0.7 0.0 ± 0.1
Polyester Blackout Liner	3	12	Front	5.3 ± 0.7 1.7 ± 2.9	0.3 ± 0.3	0 ± 0	0 ± 0	1.3 ± 0.6 [1.0 ± 0.0]	6.3 ± 1.3 1.3 ± 2.2

Table 3. Results of Small-Scale Semi-Restraint Tests (cont'd.)

Materials - Drapery - Liner	Number of Specimens	Exposure (sec.)	Place of Ignition	Char Length ± S.D. (inches)	Mass Loss ± S.D. (%)	After Flame ± S.D. (sec.)	After Glow ± S.D. (sec.)	Flame Drip # ± S.D. [sec ± S.D.	Destroyed Area ± S.D. (sq. inches)
Wool Cotton Liner	3	6	Bottom	4.6 ± 1.8 3.8 ± 1.8	0.1 ± 0.4	1.8 ± 2.8	0.2 ± 0.3	0 ± 0	4.1 ± 2.5 3.3 ± 2.0
Wool Cotton Liner	3	12	Bottom	4.5 ± 2.6 4.3 ± 2.1	1.5 ± 0.9	0.2 ± 0.3	0.5 ± 0.9	0 ± 0	5.5 ± 3.8 4.9 ± 4.3
Wool Cotton Liner	3	24	Bottom	6.5 ± 0.5 3.6 ± 2.8	1.3 ± 0.9	0 ± 0	0.2 ± 0.3	0 ± 0	7.7 ± 2.5 3.8 ± 3.9
Wool Cotton Liner	3	6	Back	3.2 ± 1.4 5.2 ± 0.3	0.6 ± 0.3	0 ± 0	0 ± 0	0 ± 0	4.5 ± 2.6 8.6 ± 1.1
Wool Cotton Liner	3	12	Back	2.3 ± 0.8 6.2 ± 0.3	1.6 ± 0.5	0 ± 0	0 ± 0	0 ± 0	2.9 ± 0.9 12.8 ± 0.8
Wool Cotton Liner	3	6	Front	5.3 ± 1.4 0 ± 0	0.0 ± 0.3	0 ± 0	0 ± 0	0 ± 0	5.9 ± 2.0 0 ± 0
Wool Cotton Liner	3	12	Front	8.3 ± 2.5 0.5 ± 0.5	1.0 ± 1.0	2.7 ± 4.6	0 ± 0	0 ± 0	17.8 ± 8.4 0.3 ± 0.4
Wool Blackout Liner	3	6	Bottom	6.4 ± 4.5 0 ± 0	0.3 ± 0.6	5.0 ± 8.7	0.3 ± 0.6	0 ± 0	8.3 ± 7.8 0 ± 0
Wool Blackout Liner	3	12	Bottom	8.3 ± 5.8 7.5 ± 7.3	7.8 ± 7.6	10.0 ± 14.0	8.3 ± 14.4	0 ± 0	13.3 ± 14.4 12.4 ± 15.6
Wool Blackout Liner	3	24	Bottom	7.3 ± 0.7 0.6 ± 0.5	0.4 ± 0.2	0 ± 0	0 ± 0	0 ± 0	11.1 ± 4.7 0.3 ± 0.2
Wool Blackout Liner	3	6	Back	0.2 ± 0.1 3.0 ± 0.3	0.2 ± 0.3	0.1 ± 0.1	0 ± 0	0 ± 0	0.0 ± 0.4 3.6 ± 0.6
Wool Blackout Liner	3	12	Back	1.2 ± 1.0 5.6 ± 0.4	0.6 ± 0.2	1.0 ± 1.7	0 ± 0	0 ± 0	1.3 ± 1.3 8.9 ± 2.8
Wool Blackout Liner	3	6	Front	5.8 ± 0.6 0 ± 0	0.0 ± 0.1	0 ± 0	0 ± 0	0 ± 0	11.8 ± 5.4 0 ± 0
Wool Blackout Liner	3	12	Front	6.8 ± 0.8 0 ± 0	0.2 ± 0.1	0.3 ± 0.6	0 ± 0	0 ± 0	19.9 ± 2.7 0 ± 0

Table 3. Results of Small-Scale Semi-Restraint Tests (cont'd.)

Materials - Drapery - Liner	Number of Specimens	Exposure (sec.)	Place of Ignition	Char Length ± S.D. (inches)	Mass Loss ± S.D. (%)	After Flame ± S.D. (sec.)	After Glow ± S.D. (sec.)	Flame Drip # ± S.D. [sec ± S.D.]	Destroyed Area ± S.D. (sq. inches)
Cotton Cotton Liner	3	6	Bottom	2.3 ± 1.1 4.3 ± 1.0	0.6 ± 0.2	0 ± 0	0 ± 0	0 ± 0	1.5 ± 1.0 4.3 ± 1.4
Cotton Cotton Liner	3	12	Bottom	3.6 ± 0.9 5.8 ± 0.3	1.3 ± 0.2	0 ± 0	0 ± 0	0 ± 0	3.1 ± 1.3 7.5 ± 1.5
Cotton Cotton Liner	3	24	Bottom	4.9 ± 1.8 6.7 ± 0.7	1.8 ± 0.8	0 ± 0	0.2 ± 0.3	0 ± 0	7.8 ± 6.9 8.4 ± 2.6
Cotton Cotton Liner	3	6	Back	0 ± 0 4.6 ± 0.9	0.4 ± 0.3	0 ± 0	0.1 ± 0.1	0 ± 0	0 ± 0 6.6 ± 1.8
Cotton Cotton Liner	3	12	Back	2.0 ± 3.5 6.2 ± 0.8	1.6 ± 0.3	0 ± 0	0 ± 0	0 ± 0	0 ± 0 10.8 ± 2.2
Cotton Cotton Liner	3	6	Front	4.2 ± 1.0 2.8 ± 0.4	0.3 ± 0.2	0 ± 0	0 ± 0	0 ± 0	5.7 ± 2.0 3.4 ± 1.3
Cotton Cotton Liner	3	12	Front	5.4 ± 0.7 3.8 ± 0.3	0.9 ± 0.3	0 ± 0	0 ± 0	0 ± 0	8.0 ± 2.5 4.7 ± 0.8
Cotton Blackout Liner	3	6	Bottom	1.9 ± 1.4 1.6 ± 1.5	0.1 ± 0.1	0.3 ± 0.6	3.2 ± 1.8	0 ± 0	1.4 ± 1.1 1.6 ± 1.5
Cotton Blackout Liner	3	12	Bottom	5.9 ± 2.2 6.0 ± 1.0	2.7 ± 2.1	0 ± 0	0.1 ± 0.1	0 ± 0	5.9 ± 2.2 8.9 ± 2.8
Cotton Blackout Liner	3	24	Bottom	2.7 ± 1.7 6.5 ± 1.1	3.1 ± 1.9	0 ± 0	4.3 ± 7.5	0 ± 0	2.7 ± 2.2 10.9 ± 7.4
Cotton Blackout Liner	3	6	Back	0.6 ± 1.0 2.1 ± 1.9	0.2 ± 0.2	0 ± 0	0 ± 0	0 ± 0	0.3 ± 0.5 1.9 ± 1.8
Cotton Blackout Liner	3	12	Back	0.3 ± 0.4 5.2 ± 0.4	1.0 ± 1.1	0 ± 0	0 ± 0	0 ± 0	0.1 ± 0.1 7.0 ± 1.9
Cotton Blackout Liner	3	6	Front	4.0 ± 0.0 3.0 ± 0.5	0.2 ± 0.2	0 ± 0	0 ± 0	0 ± 0	4.2 ± 0.3 3.9 ± 2.0
Cotton Blackout Liner	3	12	Front	5.8 ± 0.1 0.6 ± 0.6	0.5 ± 0.1	0 ± 0	0 ± 0	0 ± 0	9.2 ± 0.7 0.7 ± 0.6

* Standard Deviation (S.D.)

Table 4. Results of Large-Scale NFPA 701 Tests

Materials - Drapery - Liner	Number of Specimens	# of Test Failures	Exposure (min.)	Place of Ignition	Char Length ± S.D.* (inches)	Mass Loss ± S.D.* (%)	After Flame ± S.D.* (sec.)	After Glow ± S.D.* (sec.)	Flame Drip # ± S.D.* [sec ± S.D.*]	Destroyed Area ± S.D.* (sq. inches)
Modacrylic Cotton Liner	3^{AF}	1/3	2	Bottom	49.0 ± 30.6† 44.7 ± 34.8†	13.7 ± 11.4†	9.7 ± 16.7†	43 ± 74†	0 ± 0	960 ± 410† 820 ± 420†
Modacrylic Cotton Liner	1^{B}	0/1	2	Bottom	7.0 8.0	1.5	0	0	0	35 69
Modacrylic Blackout Liner	3^{AF}	3/3	2	Bottom	79.7 ± 4.0 68.0 ± 21.2	23.3 ± 12.4	4.7 ± 4.5†	171 ± 195†	0 ± 0	1890 ± 110 1530 ± 470
Modacrylic Blackout Liner	1^{B}	1/1	2	Bottom	59.0 34.0	6.5	0	180	0	470 660
Polyester Cotton Liner	3^{AF}	2/3	2	Bottom	24.7 ± 12.7 37.0 ± 29.1†	10.5 ± 10.5†	12.7 ± 14.8†	0 ± 0	0.7 ± 1.2† [1.0 ± 0.0]	540 ± 330† 680 ± 780†
Polyester Cotton Liner	1^{BF}	1/1	2	Bottom	5.0 8.0	1.3	7.0	2	0	20 110
Polyester Blackout Liner	3^{AF}	3/3	2	Bottom	47.0 ± 32.1† 52.7 ± 28.0†	12.4 ± 7.2†	52.3 ± 51.1†	82 ± 101†	2.3 ± 0.6 [1.3 ± 0.8]	980 ± 610† 1120 ± 720†
Polyester Blackout Liner	1^{B}	0/1	2	Bottom	8.0 7.0	4.8	0	0	0	48 53
Polyester Blackout Liner	4^{CF}	2/4	2	Bottom	29.0 ± 9.1 37.3 ± 11.2	10.1 ± 5.1	7.8 ± 15.5†	33 ± 33†	0.5 ± 1.0 [1.0 ± 0.0]	630 ± 280† 810 ± 350†
Polyester Blackout Liner	4^{DF}	2/4	2	Bottom	34.5 ± 33.8† 39.5 ± 29.8†	9.5 ± 9.5†	5.6 ± 10.9†	98 ± 165†	0 ± 0	770 ± 840† 830 ± 790†

Table 4. Results of Large-Scale NFPA 701 Tests (cont'd.)

Materials - Drapery - Liner	Number of Specimens	# of Test Failures	Exposure (min.)	Place of Ignition	Char Length ± S.D.* (inches)	Mass Loss ± S.D. (%)	After Flame ± S.D. (sec.)	After Glow ± S.D. (sec.)	Flame Drip # ± S.D. [sec ± S.D.]	Destroyed Area ± S.D. (sq. inches)
Wool Cotton Liner	3^{A}	0/3	2	Bottom	28.0 ± 11.1 31.7 ± 2.1	9.3 ± 2.6	0 ± 0	0 ± 0	0 ± 0	640 ± 300 650 ± 90
Wool Cotton Liner	1^{B}	0/1	2	Bottom	9.0 14.5	0	0	0	0	110 70
Wool Blackout Liner	4^{AF}	1/4	2	Bottom	44.5 ± 30.2† 45.5 ± 26.3†	16.9 ± 10.1†	0 ± 0	141 ± 97†	0 ± 0	850 ± 600† 1060 ± 660†
Cotton Cotton Liner	3^{A}	1/3	2	Bottom	33.3 ± 4.6 36.7 ± 8.1	15.9 ± 4.1	0 ± 0	0 ± 0	0 ± 0	740 ± 130 860 ± 220
Cotton Cotton Liner	1^{B}	0/1	2	Bottom	16.0 24.0	2.9	0	0	0	140 310
Cotton Blackout Liner	4^{AF}	3/4	2	Bottom	39.5 ± 6.5 42.8 ± 6.2	20.8 ± 2.7	0 ± 0	26 ± 24†	0 ± 0	910 ± 180 880 ± 180

* - Standard Deviation (S.D.)
† - The large standard deviation is a consequence of the wide range of measured results.
A - Test conditions include open cabinet door, burn-room door closed, exhaust system off.
B - Test conditions include an open cabinet door, burn-room door open, exhaust system on.
C - Test conditions include a closed cabinet door, burn-room door closed, exhaust system off.
D - Test conditions include an open cabinet door, burn-room door closed, exhaust system off, and separation between the fabric layers.
F - Average value of the tests would constitute a failure based on NFPA 701 criteria for char length and/or after flame.

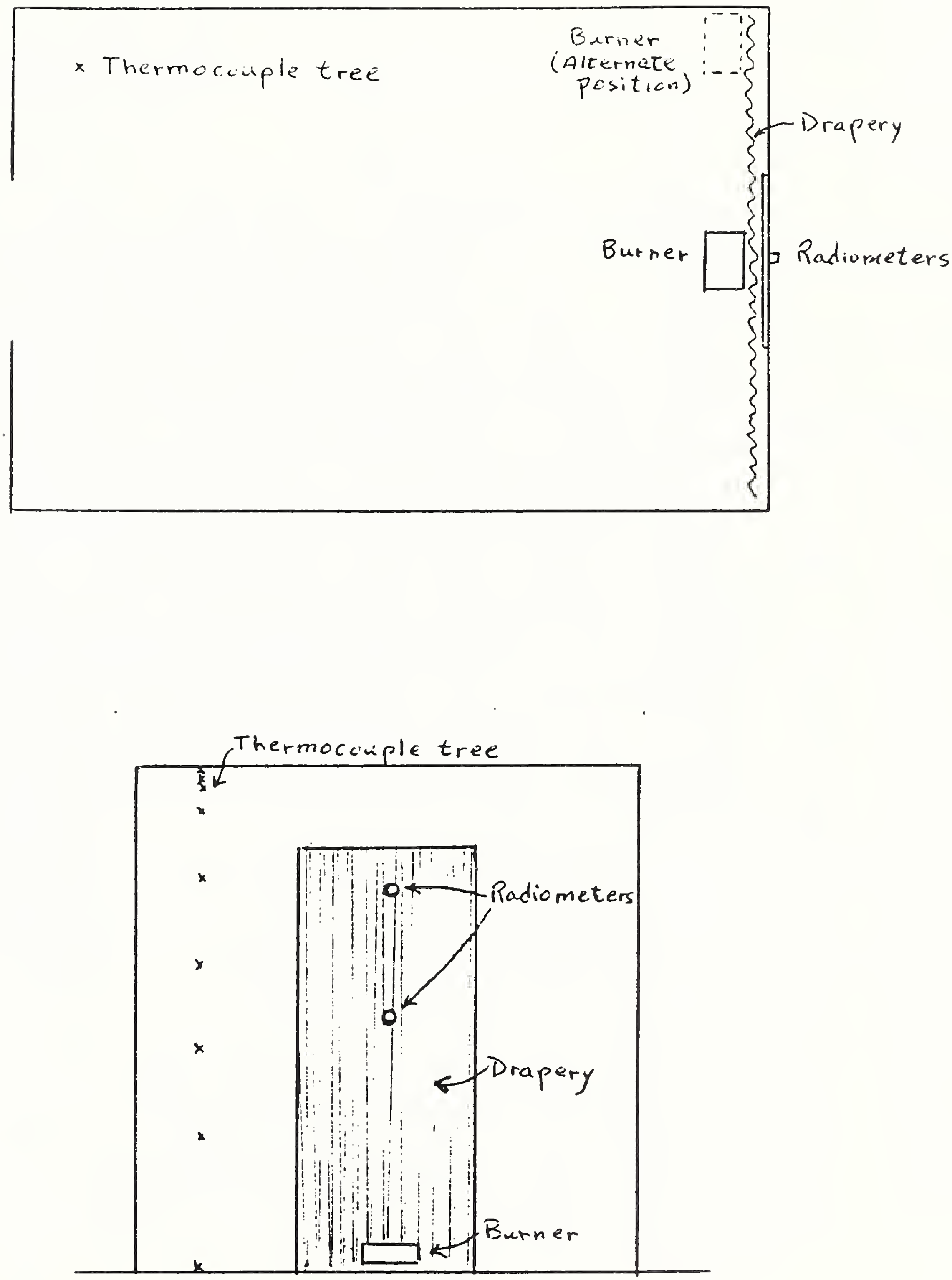


Figure 1. Full-Scale Test Room

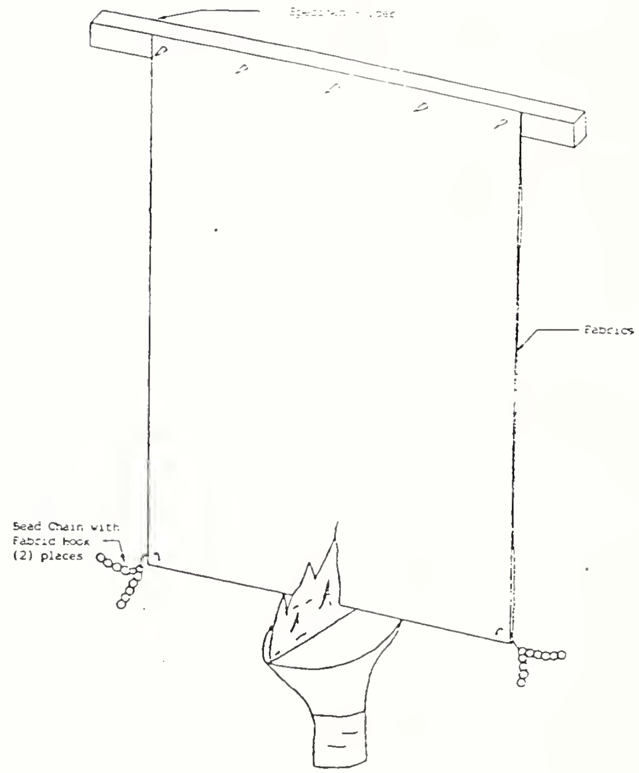


Figure 2. ASTM D 3659 Semi-Restraint Test Method Sample Configuration

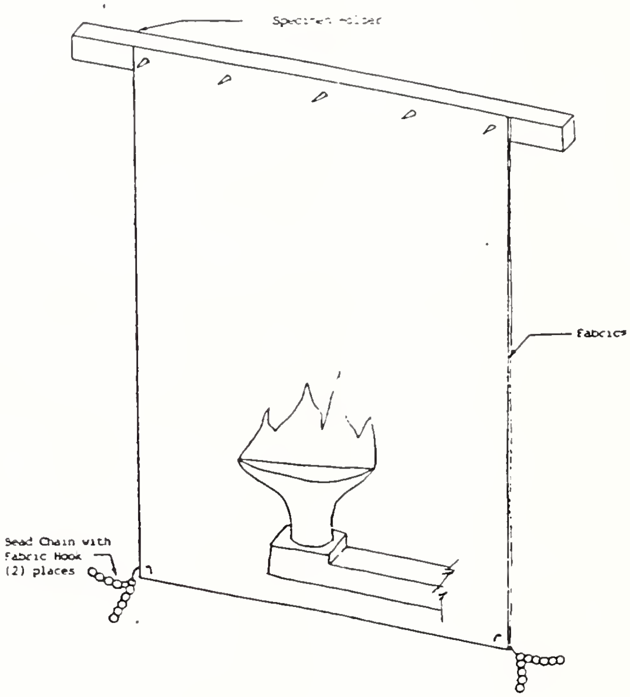


Figure 3. Semi-Restraint Test Method Sample Configuration for Front and Back Body Ignition

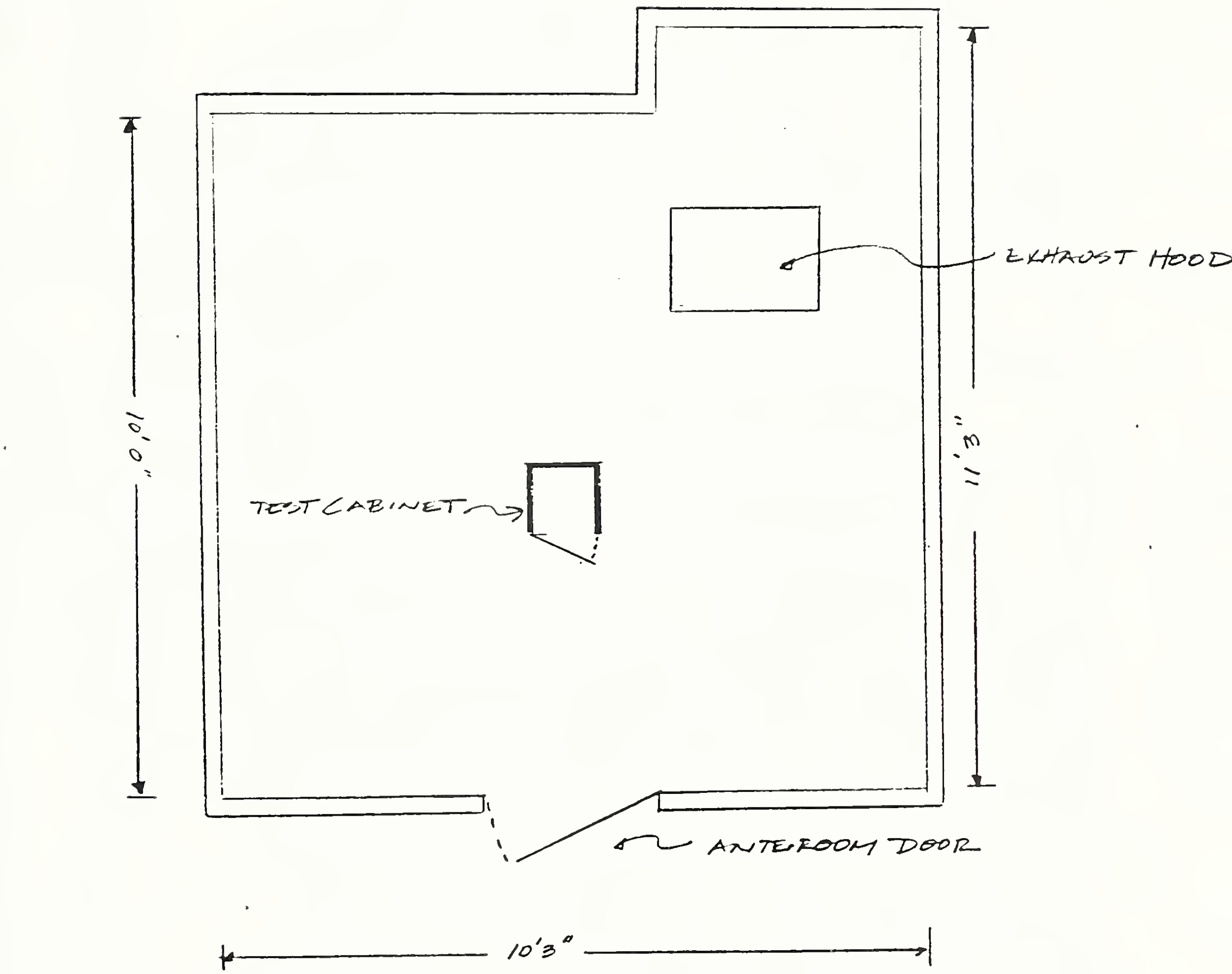


Figure 4. NFPA 701 Large-Scale Test Room Facility

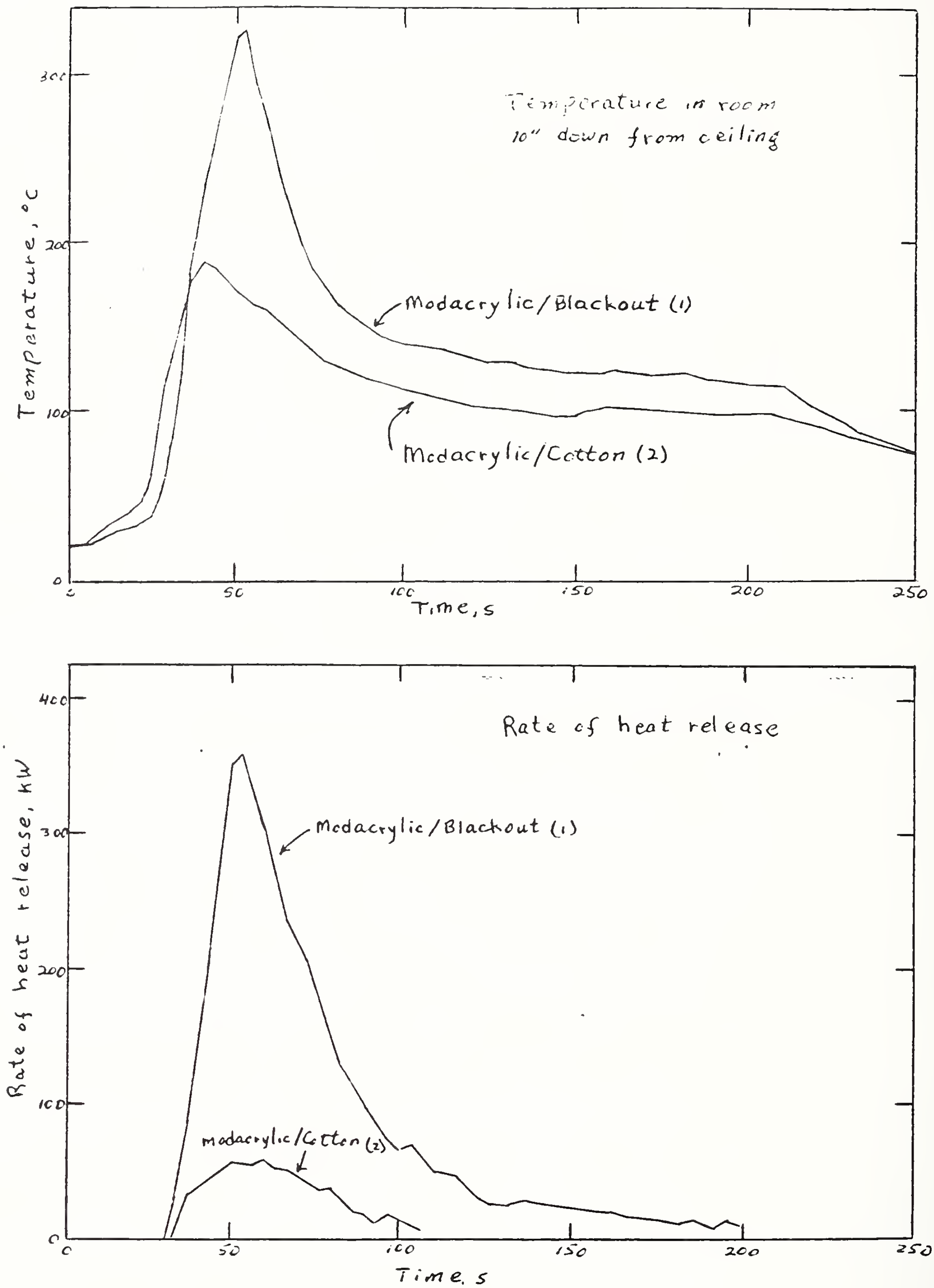


Figure 5. Full-Scale Test Results with Modacrylic Drape

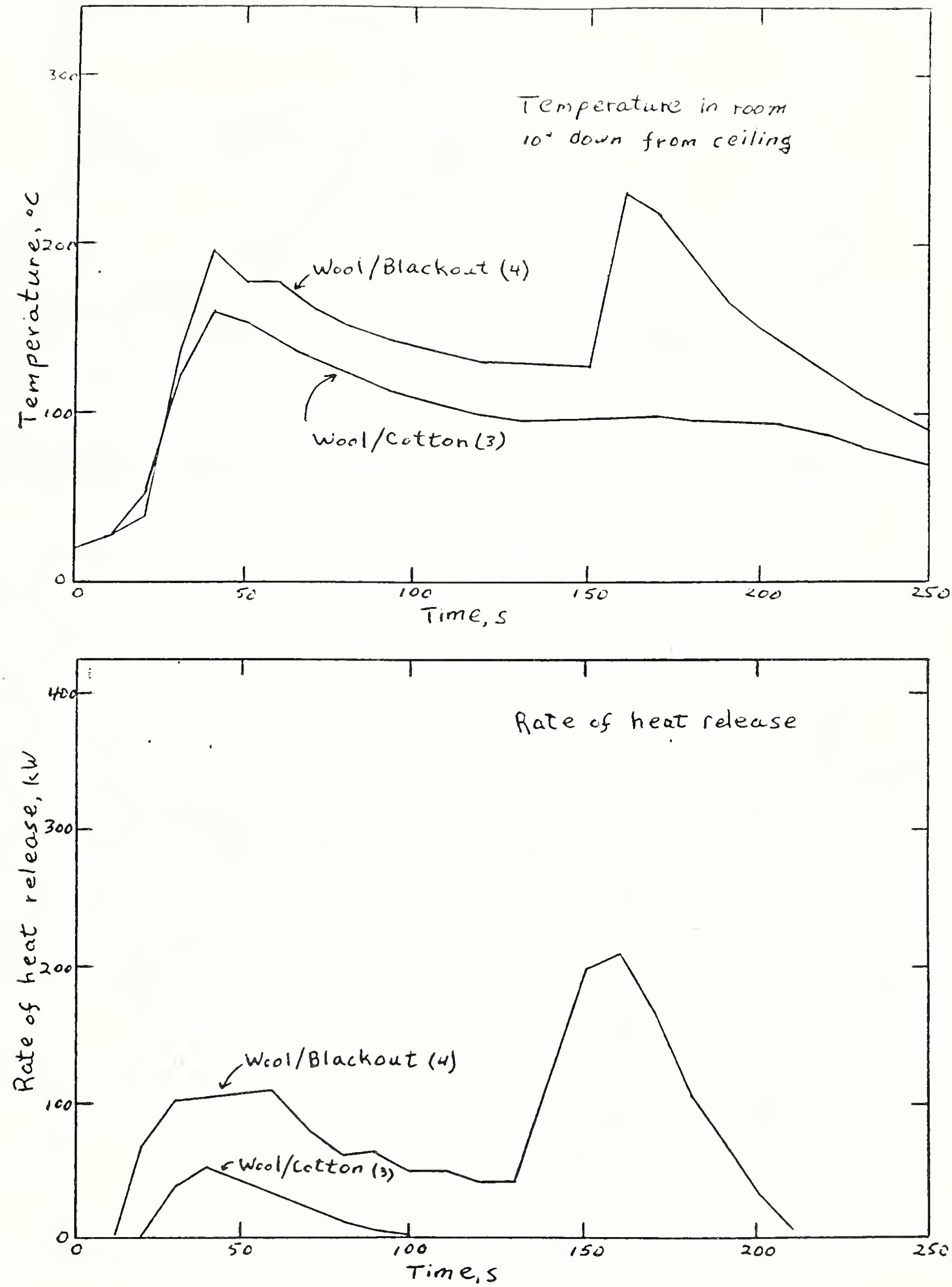


Figure 6. Full-Scale Test Results with Wool Drape

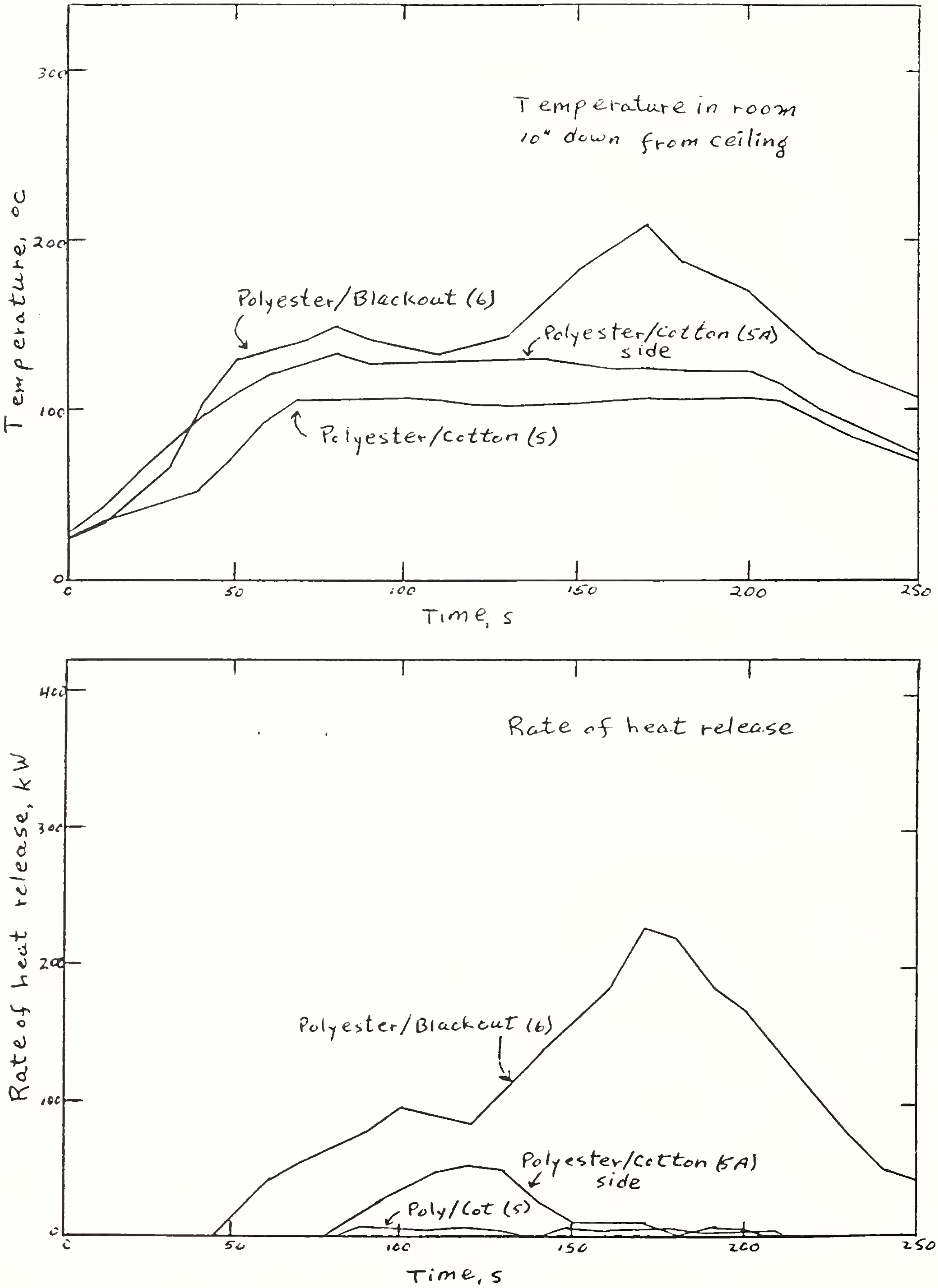
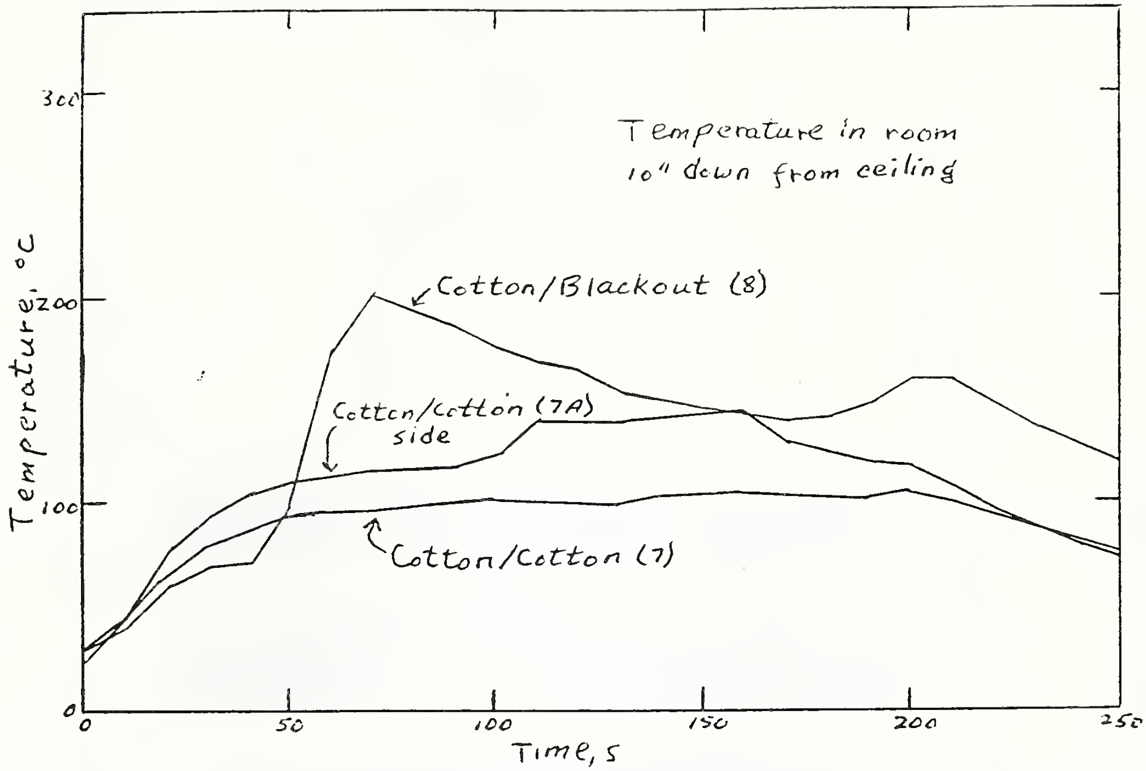


Figure 7. Full-Scale Test Results with Polyester Drape



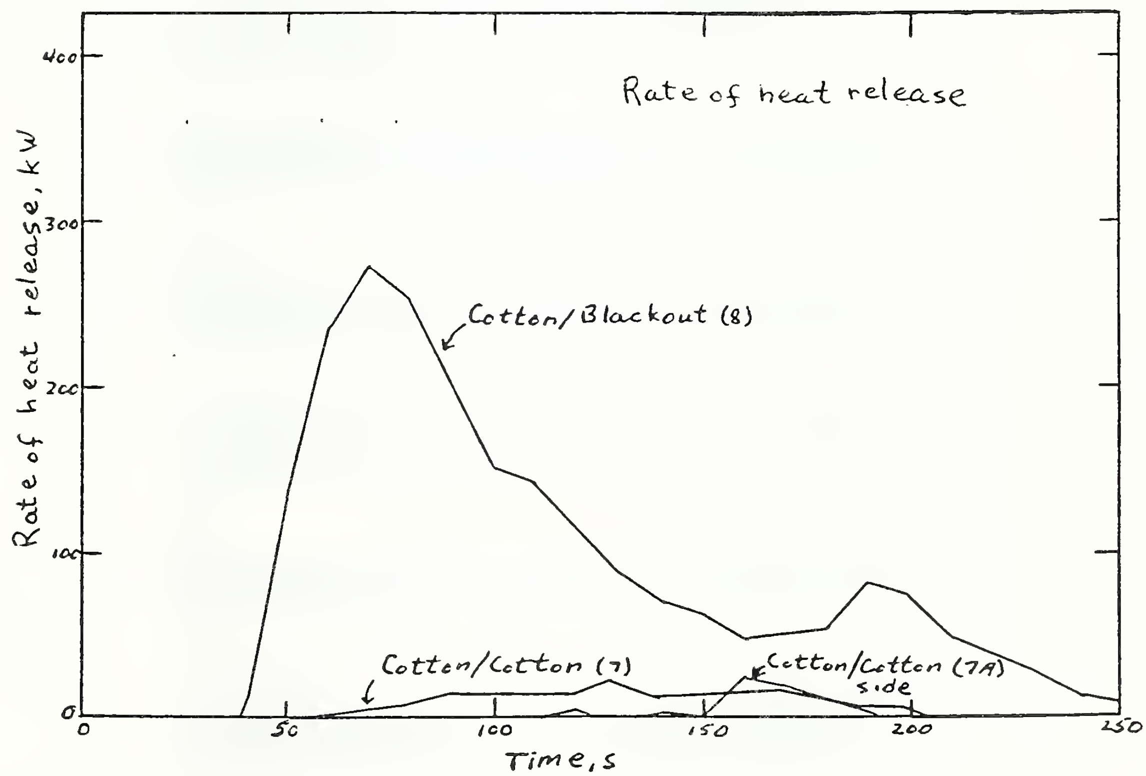


Figure 8. Full-Scale Test Results with Cotton Drape

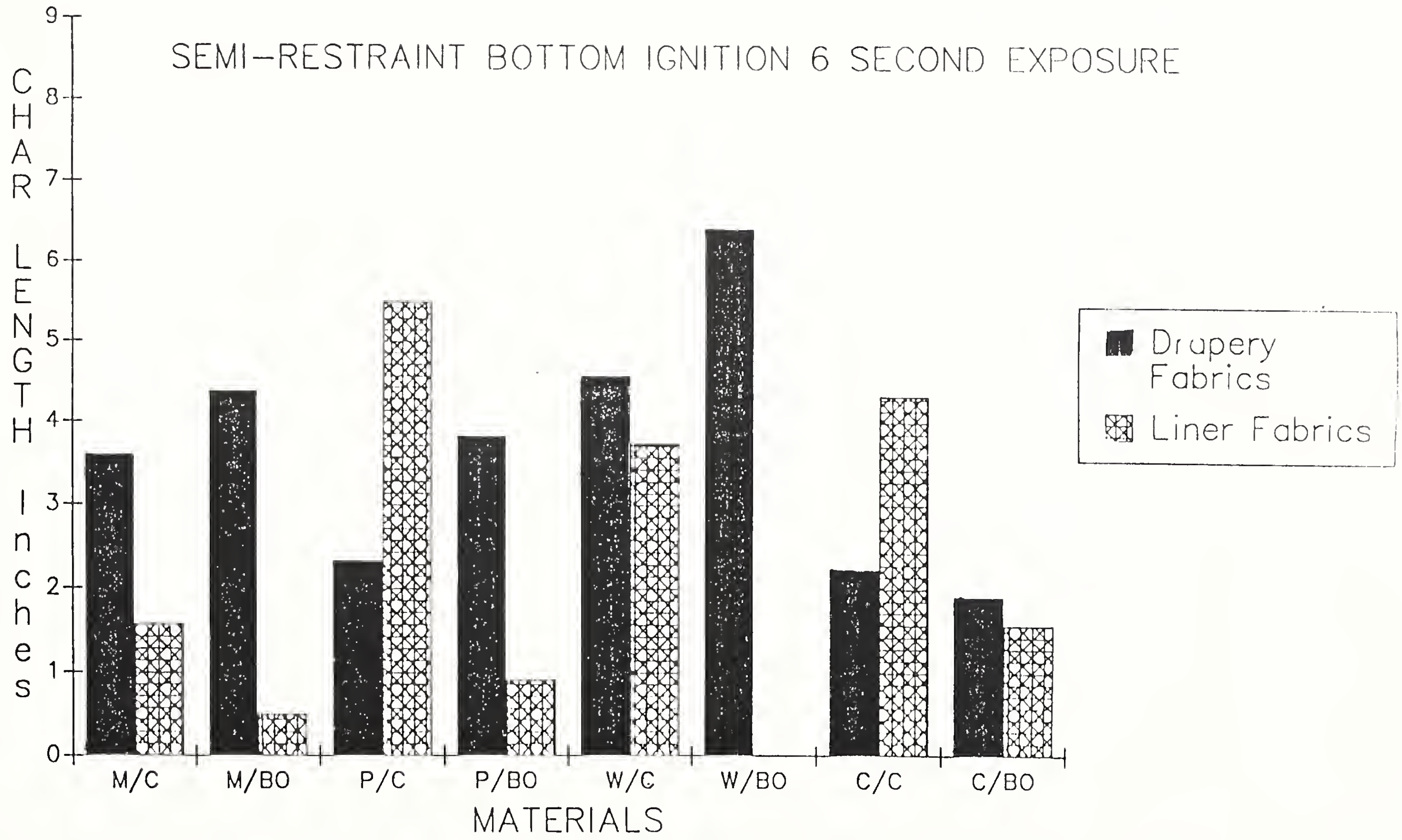


Figure 9. Semi-Restraint Tests - Bottom Ignition, 6 Second Exposure

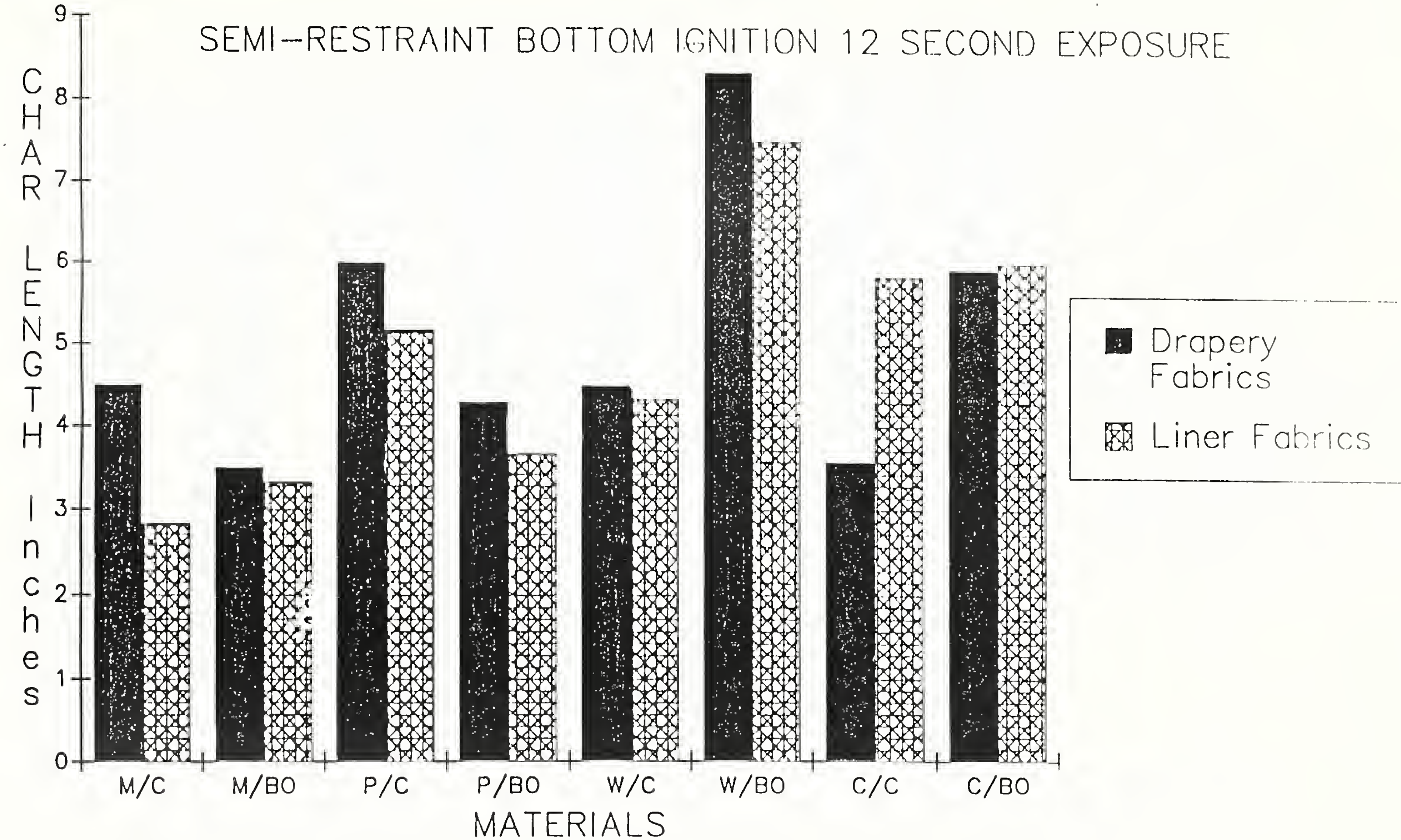


Figure 10. Semi-Restraint Tests - Bottom Ignition, 12 Second Exposure

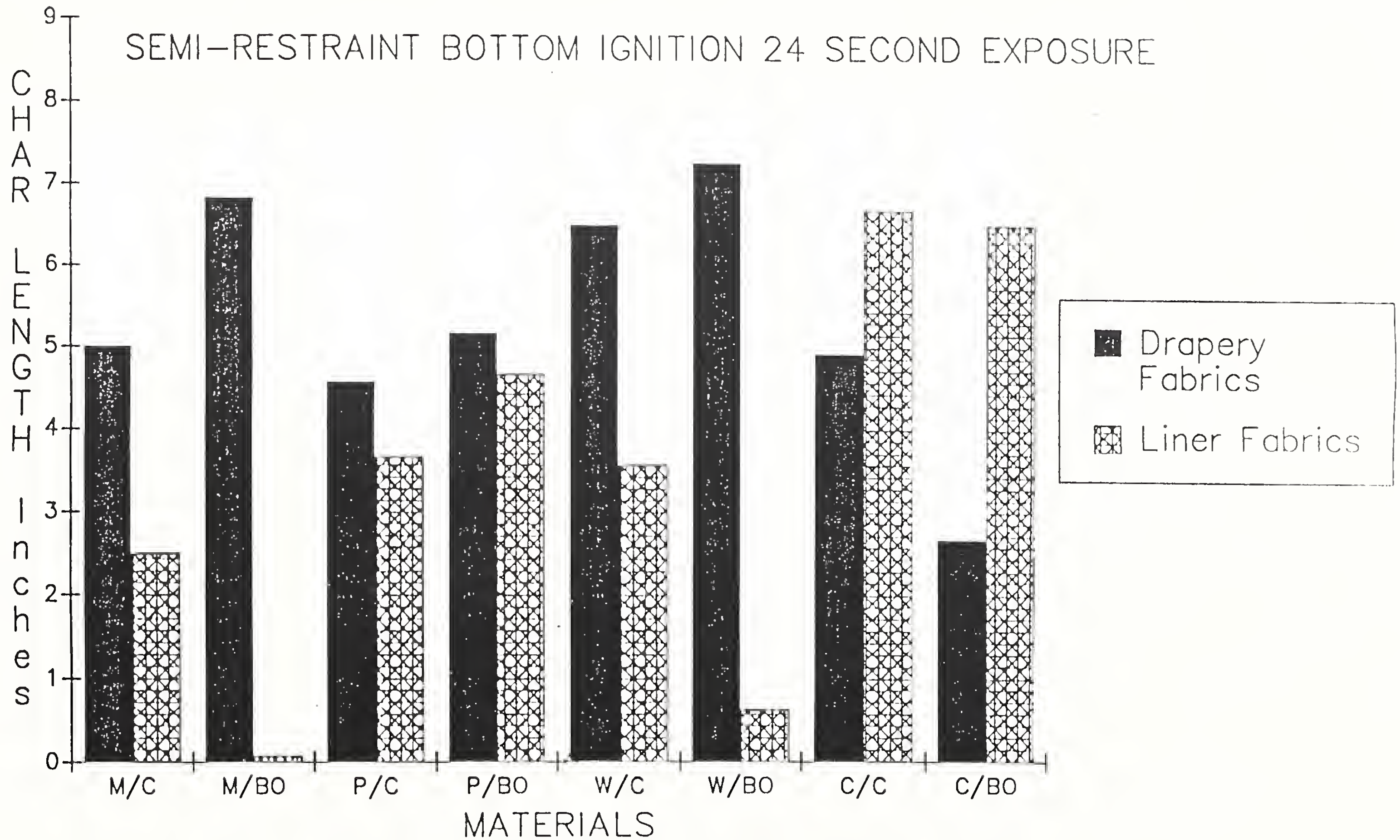


Figure 11. Semi-Restraint Tests - Bottom Ignition, 24 Second Exposure

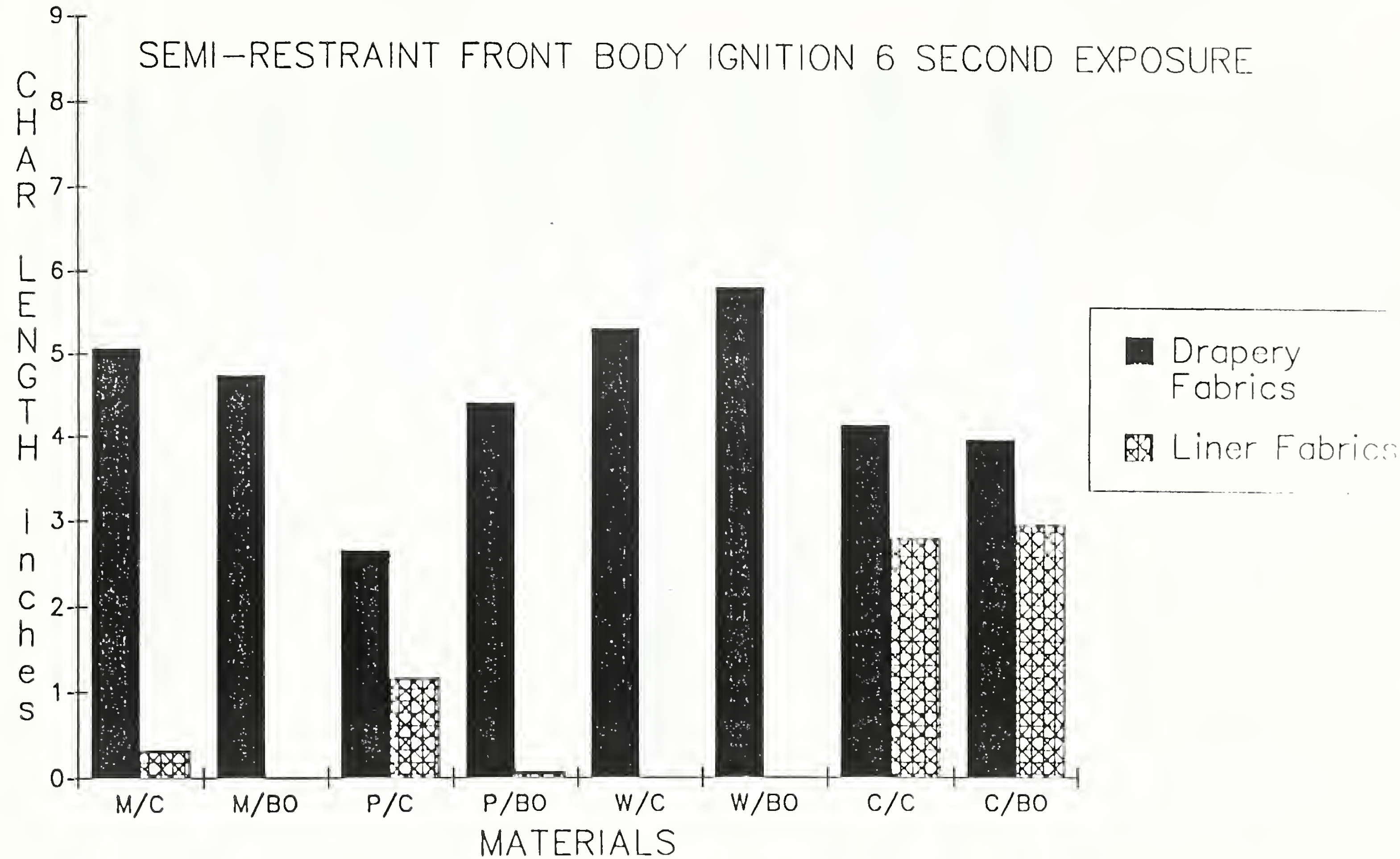


Figure 12. Semi-Restraint Tests - Front Body Ignition, 6 Second Exposure

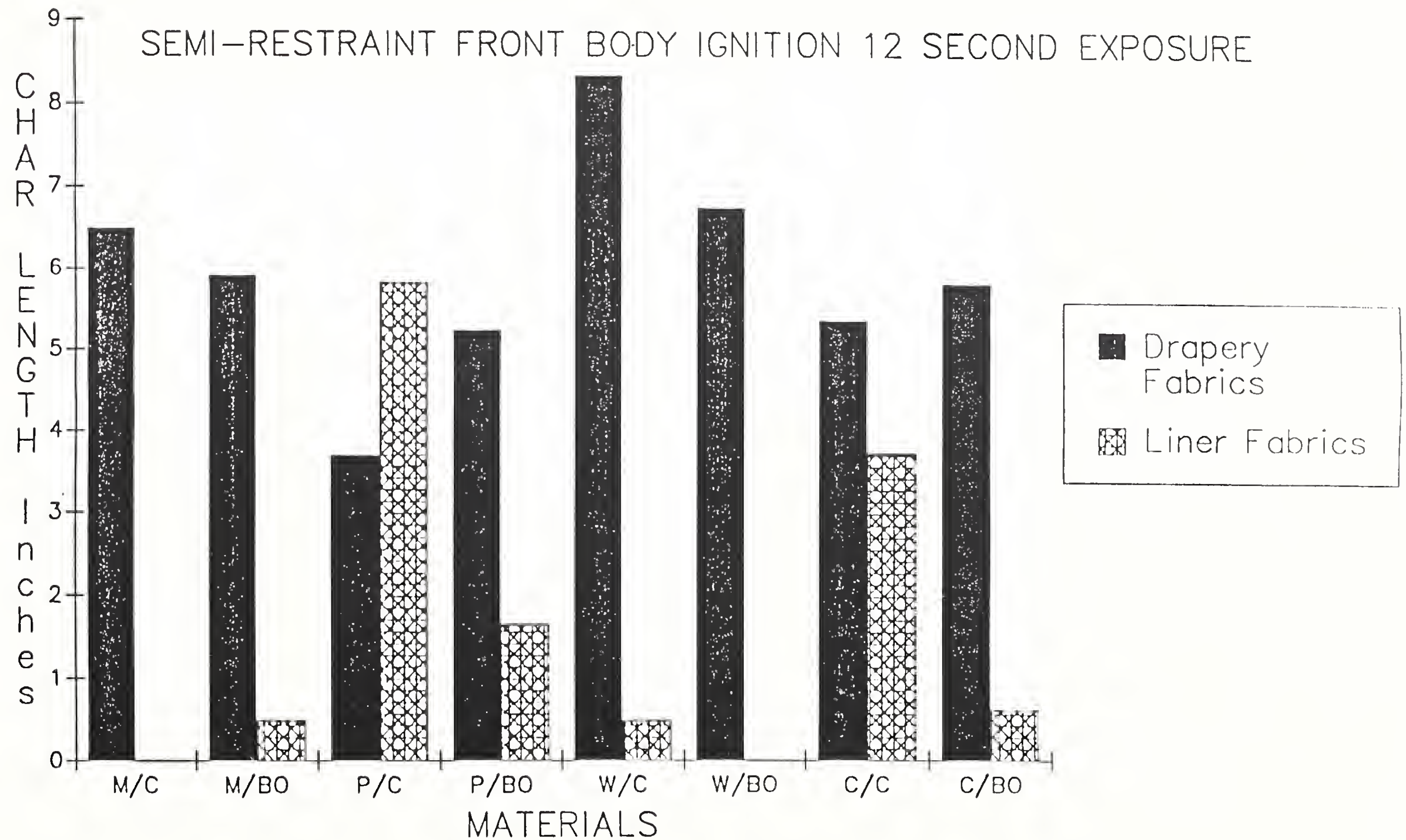


Figure 13. Semi-Restraint Tests - Front Body Ignition, 12 Second Exposure

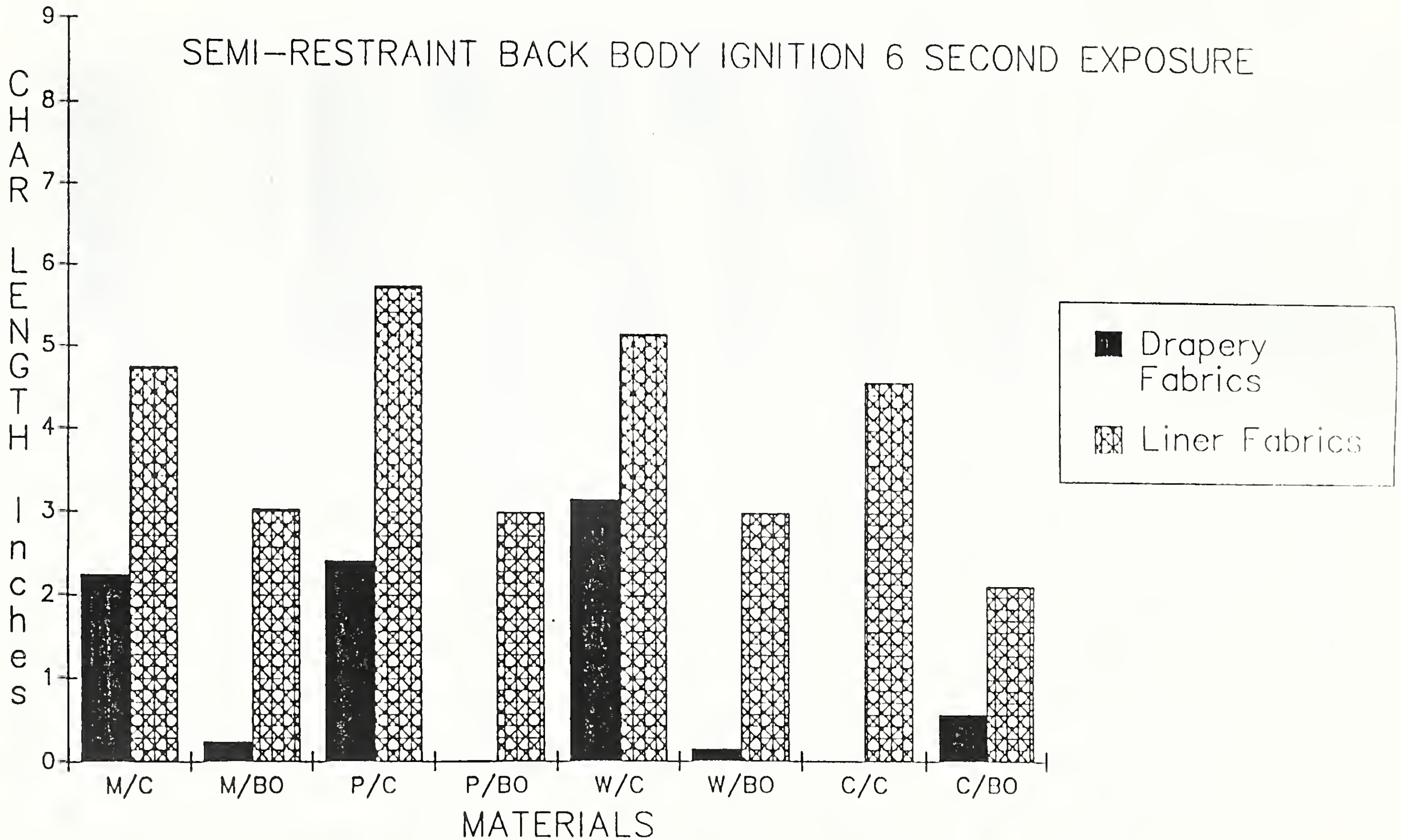


Figure 14. Semi-Restraint Tests - Back Body Ignition, 6 Second Exposure

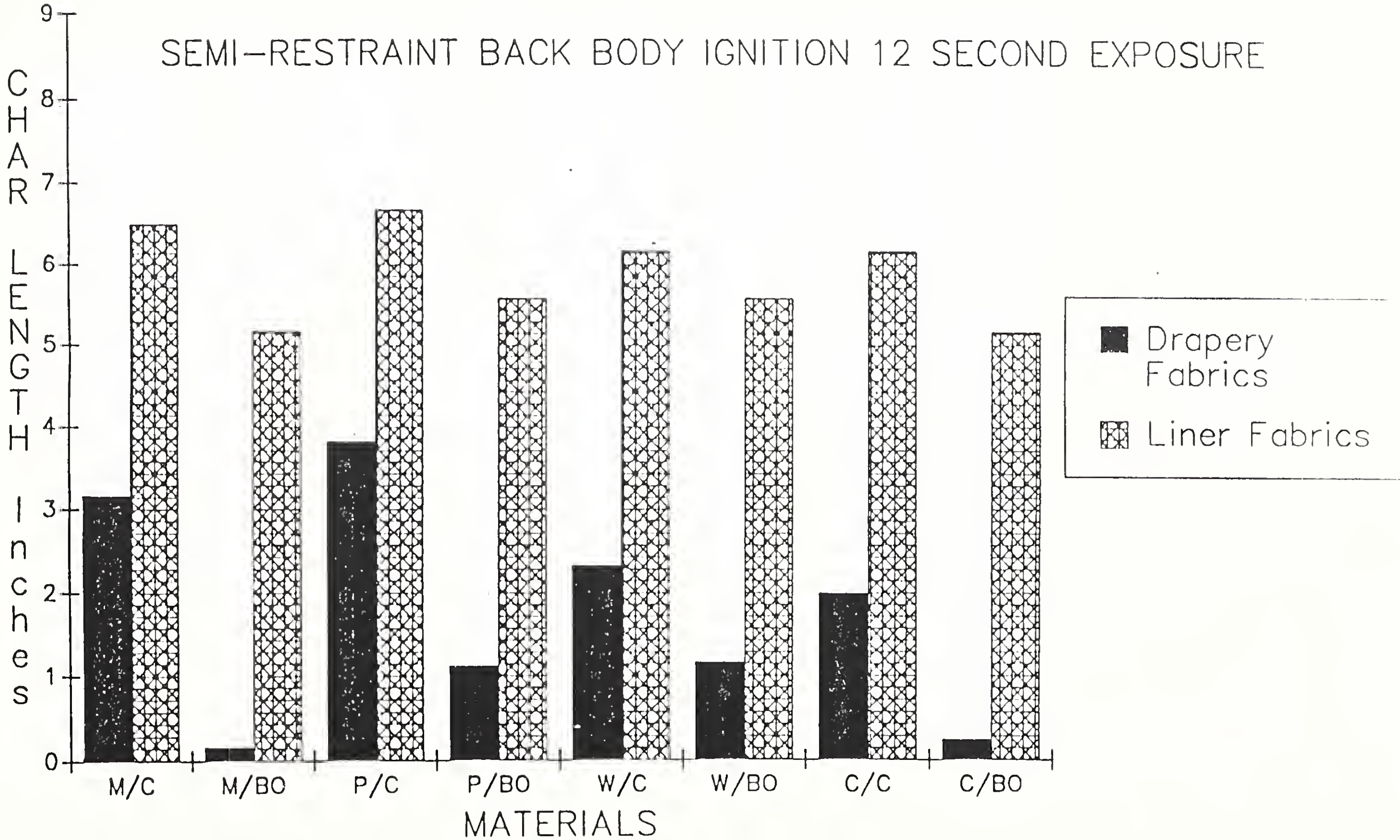


Figure 15. Semi-Restraint Tests - Back Body Ignition, 12 Second Exposure

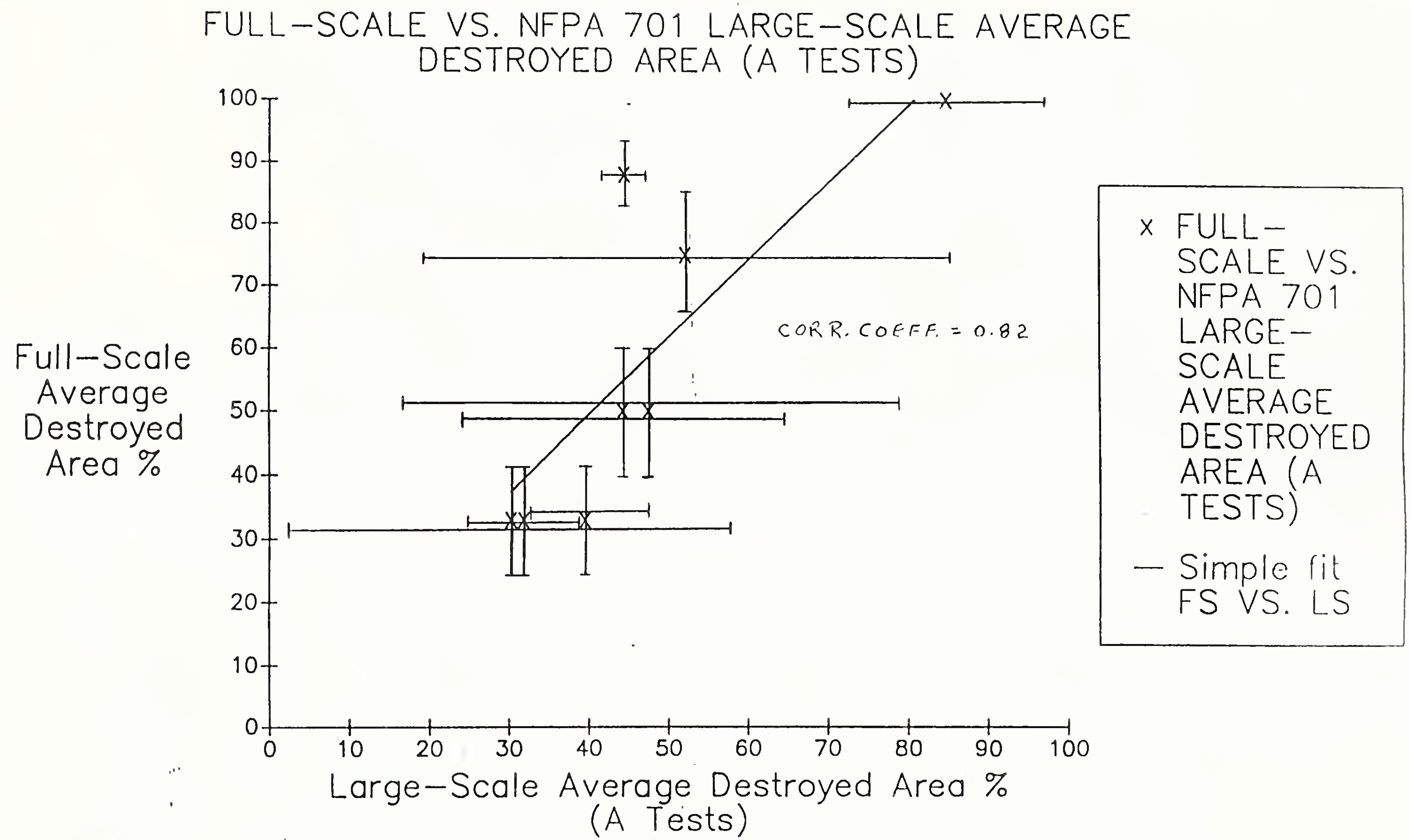


Figure 16. Full-Scale vs. NFPA 701 Large-Scale Average Destroyed Area (A Tests)

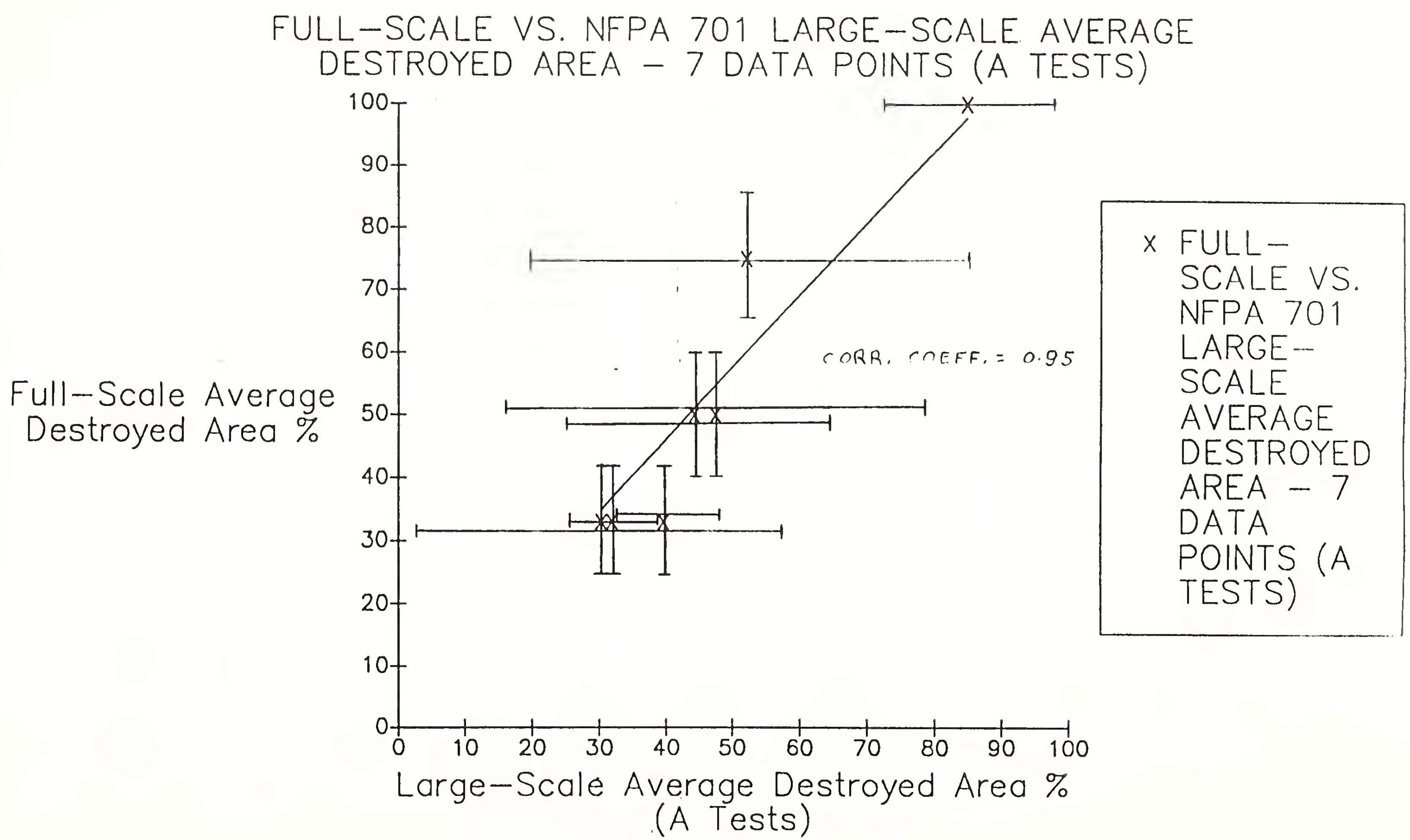


Figure 17. Full-Scale vs. NFPA 701 Large-Scale Average Destroyed Area - 7 Points (A Tests)

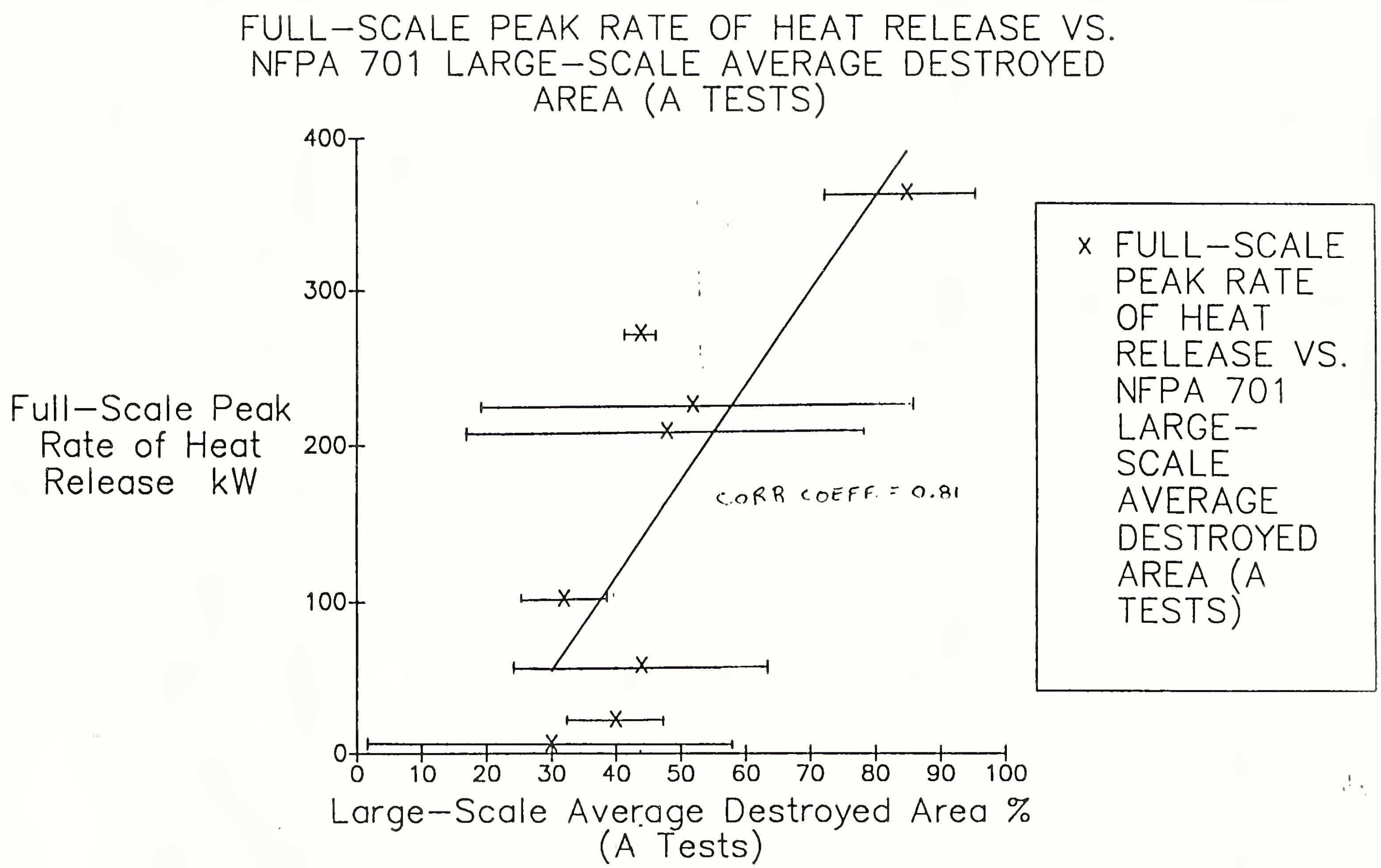


Figure 18. Full-Scale Peak Rate of Heat Release vs. NFPA 701 Large-Scale Average Destroyed Area (A Tests)

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The objectives of this research program are to investigate the flammability behavior of multiple layer fabric assemblies used for draperies and to develop a laboratory-scale test protocol for predicting full-scale fire behavior. The need for such a study arose from recent findings that showed multiple layers of fabrics, comprised of individual fabrics which meet the requirements of NFPA 701, may present a serious fire hazard. Eight combinations of four drapery fabrics and two lining fabrics were examined using variants of two established test procedures for single layers: the ASTM D3659 Semi-Restraint Test Method and the NFPA 701 Large-Scale Test Method. The conclusions from this study are that neither of these methods, as currently written, adequately predict the full-scale fire behavior of multiple layer fabric assemblies. Based on the results of this study, it is too early to recommend any test ptotocol for inclusion in NFPA 701.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

ASTM D3659; curtains; drapes; flammability; large scale fire tests; NFPA 701; textiles; small scale fire tests

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